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An Adaptive Intelligent Car Lab as a Proactive Learning Environment*

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With the continuous development of information and telecommunication technologies, intelligent control has been penetrating into every aspect of human's life. Automobile manufacturing is no exception. In particular, teaching laboratories that combine intelligent control with automobile manufacturing have recently attracted teachers' attention from various universities and colleges. The intelligent car lab presented in this paper is developed on top of a competition developed by Freescale, a semiconductor company, together with the Chinese Higher Education Automation Professional Education Committee in China. This competition is held in several Asian countries for the sake of cultivating students' practical abilities. The paper introduces the whole learning environment process, preparation made by teachers and students from Shanghai Maritime University, and the setup of a concept of adaptive intelligent car lab. We introduce the project components, technical developments achieved by the students and discuss the benefits of the whole experience. We show that throughout this proactive learning environment, students learnt a large amount of technological and design knowledge and enhanced their hands-on technical abilities, as well as learning new group-project capabilities, thus providing a solid foundation for their professional future.

Keywords: proactive engineering learning; adaptive car lab; engineering student competition

1. Introduction

Nowadays, it is largely recognized that classroom teaching cannot get a satisfactory result in engineering education alone. Several worthwhile studies have been conducted to improve undergraduate engineering student skills thanks to collaborative approaches [1]. On-line theoretical approaches have been suggested as novel distance-learning methods [2], while novel ideas have been developed to bridge the gap between academic teaching and the engineering profession [3]. A large amount of initiatives for the development of problem-oriented education experiences have been developed in engineering education [cf. 4 for a survey]. In order to promote quality-oriented engineering education of institution of higher education and cultivate college students' comprehensive ability to maximize their knowledge, it clearly appears that basic engineering practice abilities, spirit of teamwork and effective appropriation of many engineering concepts should be further developed. This also favors the development of creativity by stimulating motivation, developing skills such as group-project communication, critical thinking and leadership [5]. It also favors the evaluation of professional competences in connection with real-world problems and even professional certification as suggested in recent work [6]. As an example of this recent trend, the development of adaptive intelligent car labs has attracted the attention of teachers and students all over China (e.g., the amount of participating students is more than ten thousand every year). The first Freescale Intelligent Car Competition was held in Korea in 2000. This competition came to China in 2006, guided by the idea which is "base on the train, focus on participation, encourage exploration and pursuit of excellence". With the development of the competition, the organizing committee has gradually increased the difficulty level, such as building more complicated tracks, setting obstacles for cars, addition of creative games and so on. All these changes put forward higher constraints to the stability of the cars. The objective behind these novel parameters is not only to increase the technical difficulty of the competition, but also to get closer to real world conditions.

Adaptive "intelligent cars" can be divided into three groups according to their technical properties, namely, electromagnetism-, photo-electricity- and camera-based, according to the different road-detecting methods chosen for the setup. Regarding the electromagnetic group, intelligent cars utilize electromagnetic signals to detect the road, while regarding the camera group, intelligent cars use optical lens to detect road information. Other

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road-detecting methods all belong to the photo-electric group. For each group, participants use Freescale MCU microcontrollers to monitor the car. An intelligent car can be driven into either four or two wheels according to the rules given. Note that different kinds of intelligent cars use different car models. Until now, the competition organizing committee has launched four types of different car models, which can fully meet the demands for every kind of intelligent car [7]. Participation to this competition is a challenging task for every student. In order to rank an outstanding place in the competition, students are required to have a good command and control of both software and hardware knowledge. On the one hand, software knowledge, including computer engineering, MCU technology, programming language, control theory, data mining, communication engineering and image analysis are amongst the computing skills extremely useful for the control of intelligent cars. On the other hand, hardware knowledge, ranging from sensor and detection technology, automobile, electrical, electronic to mechanical engineering helps to build a reasonable car structure. Mastering theoretical and engineering knowledge, however, is not enough. Since this competition has been held for nine times in China, students should be creative and flexible to make breakthroughs on the basis of previous experience. Therefore, students taking part in the competition can not only enhance their theoretical knowledge and apply them to practical use, but also increase their creativity. Overall, students can develop their all-round abilities in the process of learning and building their own adaptive intelligent cars. Teachers at the Shanghai Maritime University (abbreviated as SMU hereinafter) have established a specialized adaptive intelligent car lab to fully support students practicing their abilities. This lab provides essential electrical equipment and testing track for students. Before introducing three different intelligent cars and the competition, the lab in detail, relevant learning experience from other universities and colleges are presented shortly in the next section.

2. Objectives and project organization

The Freescale Intelligent Car Competition is now a well-known worldwide competition. It is an exploratory research and organized around intelligent cars, which is geared to undergraduates around a given country. Undergraduates learn a large amount of knowledge and practice hands-on ability during the whole learning process. The Freescale Intelligent Car Competition is held every year, and the subject is published by the intelligent car committee in their official website every November, while the competition will be held in the following year from July to August. Students can have enough time to prepare the competition; while teachers from SMU prepare the competition at the adaptive intelligent car lab also begin to undertake the enrolment. Every applicant can apply to the competition on campus while only the top ones can go further for the Freescale competition. Participating in this competition is then a challenging task.

Applicants are full-time undergraduates of the SMU. They are separated into several teams according to their own will. Each group consists of at most three students. The team picks their own direction and goals freely according to the regulations of the electromagnetism, photo-electricity and camera groups, according to different road-detecting methods. It is worth mentioning that the work required to manufacture an intelligent car is a non-straightforward task. Participants have about six months to prepare the competition on campus. At first, tutors and older team members introduce the basic engineering knowledge and the elementary design operations required to every team. However, there is a Chinese old saying: *give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime!* Soon after, participants begin to learn by themselves. In order to get an outstanding ranking in the competition, students should have and develop a good understanding of the software and hardware challenges of the whole process. When it comes to practice, and in order to maximize the efficiency of the group, the team distributes the tasks among its members and nominates a team leader. This also has the advantage of securing better grades at the end of the process. Students who have programming skills and good knowledge of modern control theory will be in charge of the software development, while the ones with better hardware knowledge will be rather orientated towards the design of the hardware circuit. The ones with creativity design abilities will be in charge of the design of the mechanical structure.

At the initial steps of the conception of an intelligent car, a team should first consider the mechanical structure of the car and the design of the hardware circuit, this playing an important role in the speed performance of the car. A series of experiments are in all cases carried out. All teams draw up several plans, and then develop a high number of experiments in the adaptive intelligent car labs to converge towards the best possible design. Every car in a group competes on top of a given track, and performs a course on a resulting time which is recorded, the shorter the time the better the grade. Their goals are mainly to make their car running quicker and quicker. The circuit routes on which students test their cars are shown in Fig. 1.

Fig. 1. Circuit routes in the adaptive lab.

It should be noted that the rhythm of the competition is relatively rapid. Every year, after doing a series of experiments over and over on their lab, participants are faced with their first challenge: the competition on campus in May. The ones who gain outstanding grades are selected for the Freescale Intelligent Car Competition in Eastern China to take place in July. In the same way, the better ones go further to a nation-wide competition in August. Every competition from the campus one to the one at the level of the whole country is followed by an award ceremony. It is no wonder that the experience is the most important whatever the results are.

3. Technical background

Several universities, such as Shanghai Jiao Tong University, University of Science and Technology of Beijing, Southeast University, Hangzhou Dianzi University, and ChangShu Institute of technology have gained outstanding achievements in the past intelligent car competitions. All these schools share and broadcast their successful experience regarding the hardware and software developments to the other teams. These reports summarize the hardware and software developments done, as well as the experiments achieved.

Regarding the hardware part, it appears for instance that adjusting the kingpin inclination angle and the kingpin caster angle properly increase the speed and improve the directional stability of the intelligent car [8]. For example, students of the Shanghai Jiao Tong University changed the kingpin caster angle of about 1 degree to reduce the load of the steering engine. Team members at the Chang-Shu Institute of Technology combine theoretical and practical methods to calculate these parameters. The test result turns to be accordant with their expectations. The installation of the steering engine also counts a lot on the corresponding speed of direction change, this being shown in Fig. 2. Students should also take several additional factors into consideration. Such factors include the engine load, control frequency, and the length of the arm of force. Participants of the Shanghai Second Polytechnic University finally decide to install the steering engine horizontally with two 30 cm-length arms of force.

Regarding the software part, there are a range of hundreds of choices and combinations of control-based algorithms to monitor the car and to perform self-road-detections. The options available to develop control-based algorithms include traditional PID algorithms [9], fuzzy control [10], bang-bang control [11] to mention a few of the most important components. Usually team members select and combine several algorithms. Students at the Harbin Institute of Technology pick traditional PID and bang-bang as their final controlling method. Students at the University of Science and Technology of Beijing even carry out different experiments according to the car's route, linear or curved, to identify a suitable control method. As their experiments proceed, they draw five pictures (Fig. 3) to show the pros and cons in the condition of curve. In each Figure the abscissa axis represents to the difference between the track center and the car center, while the ordinate represents the angle. By comparing different pictures, students can design a comprehensive strategy.

Besides, successful participants of this intelligent car competition often generate some valuable engineering breakthroughs. For instance, in 2010, the University of Science and Technology of Beijing first applied dynamic PID algorithm to their intelligent camera car [12]. In the 8th competition, the committee set a series of obstacles on the track to increase the difficulty level. They immediately utilized a gyroscope to detect obstacles, ensuring that the car would not rush outside of the track in high speed. In the 9th competition, students in the balance group from the Southeast University and other universities used a brand new car model and won eminent prizes. All these universities and institutes attach a high importance to this intelligent car competition and set up comprehensive intelligent car laboratories for their students. In the lab, there is enough space and integrated system and tools for students to test and adjust their own cars again and again. Therefore, these universities and institutes have gained quite impressive results in the competitions.

4. Technical components

This section introduces the principles and technical components of three sorts of intelligent cars based on the 9th Freescale Intelligent Car Competition whose regulations are first introduced. Therefore, a list of competition results gained by SMU is given.

4.1 Principles and technical components

According to the regulations of the 9th Freescale Intelligent Car Competition, both electromagnetic and photoelectric cars should use a four-wheel model, while for the camera group, cars only use two wheels. For the electromagnetic and photoelectric groups, cars are driven by rear wheels and direction is controlled by front wheels. For the camera balance group, cars are required to use two wheels to keep balance, control direction and speed. The committee also rules different car models for three car groups, so students can design their own intelligent cars on the basis of these given models. The electromagnetic group should only use the Model C, and the photoelectric group the Model B. Competitors from camera car group can pick one car model from the Models D and E. In order to simulate students' innovation ability and avoid the emergence of plagiarism, the competition organizing committee changes these models every year. The following section will discuss two main Freescale MCUs and the working principles of each car and group.

4.1.1 Two freescale MCUs: S12 and K60

In the adaptive intelligent car lab developed at the SMU, the two most wide-used MCUs are MC9S12XS128 (abbreviated as S12 hereinafter) [13] and MK60DN512LVQ10 (abbreviated as K60 hereinafter) [14]. In early competitions, students were only allowed to use S12 as intelligent car's MCU. However, with the increase of the competition difficulty level, S12 becomes more or less insufficient to handle all the technical requirements. Therefore, Freescale produced K60 to satisfy the students' needs. However, performances and abilities of S12 and K60 are widely divergent. First of all, S12 uses a 16-Bit micro controller while K60 uses ARM Cortex-M4, a 32-Bit micro controller as its core. Secondly, S12 is powered by 5V direct power supply but K60 is more energy-friendly, which only needs 3.3V. Thirdly, S12 family provides memory options from 64K, 128K to 256K byte Flash, while K60 family offers user with 256k and 512k byte Flash. What's more, K60 family provides Direct Memory Access (DMA) controller with multiplexer to increase available DMA requests, which cannot be done by using S12. In S12, the Phase-locked-loop (PLL) clock frequency multiplier can increase the clock working frequency up to 80MHz, nonetheless PLL clock frequency multiplier in K60 can raise the clock working frequency up to 200MHz. Overall, it appears that K60 has a much higher overall performance than S12. Table 1 concludes the comparisons listed before.

S12 and K60 also have a lot of modules in common. For example, they both have Pulse Width Modulator (PWM), Analogue-to-Digital Converter (ATD), Timer (TIM), Periodic Interrupt Timer (PIT). These modules can respond to the sensors and execute appropriate instructions to control the car. Besides, communication modules such as UART, SPI, CAN achieve information sharing between the host and client computers. As a result, with the aid of these modules, both S12 and K60 can control the intelligent car. After mastering one of those MCUs, students will gain the ability of using those MCUs. When they meet a new type of MCU, they will master it relatively quickly, this being based on their previous knowledge.

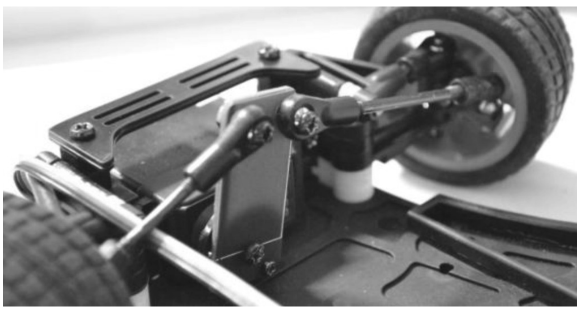

Fig. 2. Steering engine installation.

4.1.2 Electromagnetic car

For the competition, there is a copper conductor buried underneath the track. It is connected with a 100 mA current power supply. The copper conductor can generate an electromagnetic signal. The electromagnetic car uses several electric components to detect this signal and runs on the track automatically. As mentioned above, in the 9th competition, participants in the electromagnetic car group should only use car model C to design their cars. Car model C provides participants with one digital servo FUTABA 3010 and two motors

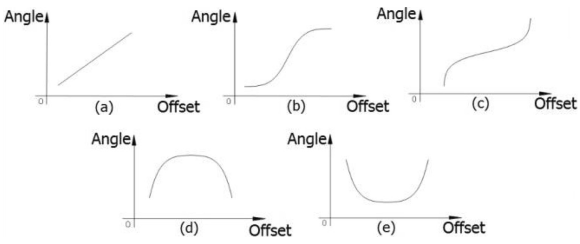

Fig. 3. Different car performances.

RN-260. Fig. 4 shows the general view of a car model C.

Besides what is provided by the car model, the car system made by SMU students also consists of a K60, eight electromagnetic sensors, one OLED, several power-supply and motor driver chips. Fig. 5 shows its general appearance.

The power supply circuits consist of one AMS1117-3.3V, providing power supply for MCU, one LM2940 and one LM1084 which supply 5v for different modules (such as LMV358, DC motor driver, speed detections and so on). The power of servo is supplied by the direct reduction voltage in series with the battery via two Schottky diodes. Speed motors are driven by the battery directly. Two car motors can be controlled by PWM waves after adding motor driven circuit. One motor driven circuit comprises two BTN7971s, each of which is an integrated high current half bridge. Four BTN7971s are needed to control two motors. The motor driven circuit for model C is shown in Fig. 5.

This electromagnetic setup supports eight inductances of 10mH as electromagnetic sensors detect track information. Lying horizontally with the track, the inductance will detect stronger electromagnetic signals when the distance between the inductance and the copper conductor become shorter. The displacement of these inductances is shown in Fig. 5. Students can use the voltage of inductances to identify road situation and enable the car to follow the track correctly. Because the original electromagnetic signals detected by the inductances are relatively small, amplifiers are needed to magnify the original electromagnetic signals. As shown in the lower part of the Fig. 5, there are 4 amplify circuits (LMV358) in the Printed Circuit Board (PCB). Their usage is to magnify the signals from the sensors and transfer them to the MCU. This intelligent car uses two motors. As shown in Fig. 5, two encoders are needed to achieve speed close-loop control.

4.1.3 Photoelectric car

The committee rules that the background of the track of this competition is white with two black guidelines at both sides of the track. The background outside the track is dark-color based. Because of this distinct color comparison between the track and guidelines, photoelectric sensors, usually linear CCDs, can be used to detect the track information and then control the car to follow the guidelines automatically. Participants in the photoelectric car group are required to use the car model B, which consists of one analogue servo S-D5, and one motor 540. Its general view is shown in Fig. 6.

As shown in Fig. 7, the photoelectric car made by SMU also comprises a S12, two linear CCD sensors, one servo motor, one speed motor, one encoder, one OLED and several power-supply and motor driver chips.

Power supply circuit is slightly different between electromagnetic and photoelectric cars. Because S12 should be powered by 5V DC supplier, the system uses LM1084-5V to provide power. Another difference concerns the motor. Motor 540 can only be powered by 12V DC supplier. Therefore, a boost circuit is needed to drive the motor. This can be achieved with the help of LM2577-ADJ, which can generate a higher output voltage with lower input voltage. Since the motors used for the electromagnetic and photoelectric cars are different, they also have distinctive motor driven circuits. As shown in Fig. 7, a photoelectric car uses four MOSFETs to drive the motor. By setting MOSFETs on or off, the motor rotates in the forward or backward direction. By inputting different PWM waves, the motor rotation speed varies.

This photoelectric car uses two linear CCDs to detect the track information. The working principle of the linear CCD is based on optical comparisons. Generally, the stronger the light, the higher voltage will be generated on the CCD. Linear CCD is an analogue device that can capture one line of 128 dots distributed on the track in each sampling period. Because of the sharp comparison between the track and guideline, students can use the binaryzation method to change the grey image, the black and white ones to extract the guidelines. This method helps to reduce MCU loads. Therefore, programmers should first select a proper threshold value to binary the line and extract the guidelines. The results can be divided into 0s (representing black)

Table 1. Main differences between S12 & K60 micro-controllers

	S12	**K60**
Core	16-Bit micro controller	32-Bit ARM Cortex-M4
Power	5V	3.3V
Memory	64K, 128K and 256K byte Flash	256k and 512k byte Flash with DMA
PLL Clock	Up to 80MHz	Up to 200MHz

Fig. 4. General View of Car Model C.

and 255s (white). Suppose that the track information is temporarily saved in a one dimensional array buffer, every time by subtracting two adjacent elements, the computer will get three possible results, 0, –255 and 255. If the result is not null, this means that the sensor detects a black guideline. Then through analyzing the location of these guidelines, students can judge the road situation. The mechanical arrangement of two linear CCDs is shown below.

Similar to the detecting principle of the electromagnetic cars, the upper linear CCD is used to detect the track information far away from the car, as shown in Fig. 7. The further road situation it can foresee, the quicker response it will make to control the car. While the lower one is to see the road situation near the car. Because linear CCD can only see one line each time, it might not detect any guideline in one sampling period. Therefore, students should take both linear CCDs' sampling results into account to make a precise judgment of the road information. Only one encoder (speed sensor) is needed to achieve a speed close-loop control because the car model B only has one motor. Students in photoelectric group use a kind of encoder which is different from the one used in electromagnetic group. This encoder shown in Fig. 7 is smaller but encompasses a higher precision.

4.1.4 Camera car

This year, that is, in 2014, the competition committee provides two different car models for camera car, namely model D and E. Model E is a brand new type of car model provided by the committee. Their appearances are illustrated in Figs 8 and 9 respectively.

These two car models are tremendously different from the car models which have been introduced above. As can be seen from the figures above, both these two car models only have two wheels and do not have servo steer. There are slight differences between these two camera car models, too. First of all, their motors are different. Car model D uses the same motor as car model C, while car model E uses

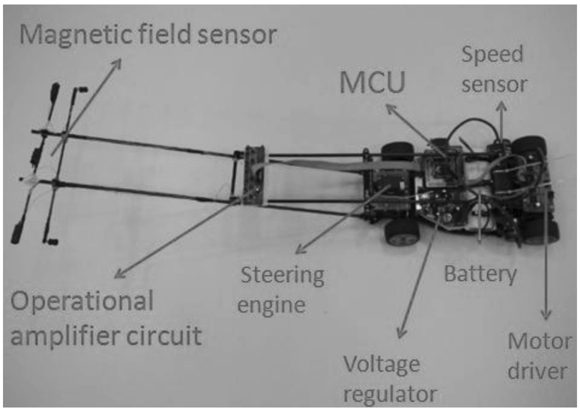

Fig. 5. General appearance of the electromagnetic car.

RS-380 as its motor. Secondly, the diameter of model E's wheels is bigger than model D's. Participants can choose their ideal car model. Students at the SMU chose to use the model D. Besides the car model, their car system also consists of one K60, one SONY CCD camera, an erect module, two encoders, several power-supply and motor driver chips. Fig. 10 shows its general appearance.

Among the system, K60 and erect module are powered by AMS1117-3.3V. The powers of two encoders and four motor drivers, BTN7971, are supplied by 1084-5V. Moreover, the SONY CCD camera's rated voltage is 12V. Accordingly, an AMS1117-ADJ is also needed. All these power circuits have been discussed above.

In order to control an intelligent camera, participants should not only consider the image process but also control the car posture and direction altogether properly within limited time. Regarding the image sampling and processing part, a camera, a Sony CDD, detects the track information firstly. The basic working principle of SONY CCD is similar to linear CCD. However, instead of getting only one line of track information, a camera can obtain an area sector from the track.

MCU uses similar methods to extract black lines from image as photoelectric cars do. However, for the camera group, track information is saved in a large two-dimensional array buffer, if the program need to abstract every two numbers in the array, it will takes a lot of time and might generate many errors. Luckily, since the guideline is continuous, if the first two lines of black lines are detected correctly, the following program should only scan a small range of numbers to see whether there is a black line. Every image covers a wide range of tracks; consequently, by following the black line, the MCU can judge in advance direction and speed parameters.

For the vertical part, MCU reads the feedback from the erect module, shown in Fig. 10, to keep the

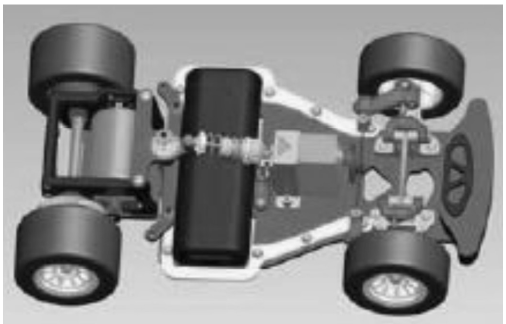

Fig. 6. General view of car model B.

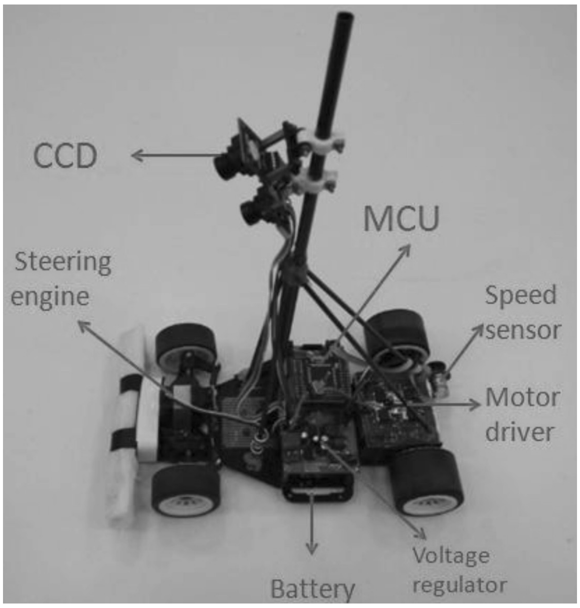

Fig. 7. General appearance of the photoelectric car.

balance of the car. In this car system, the erect module includes two gyroscopes and one angular accelerometer. Both the gyroscope (ENC03) in the z axis and the angular accelerometer (MMA7361) have some specific algebraic relationships with the angular speed of the intelligent car. Accordingly, used together, they can calculate the car's angular speed in order to keep it from falling down. Gyroscope in the y axis can sense a rollover tendency, especially when passing a curve in high speed, thus protecting the car from falling down. Only when these three parts are combined properly can the whole intelligent car system work successfully. The flowchart of the program is shown in Fig. 11.

As for the electromagnetic car, camera cars use two encoders to achieve speed close-loop control. By adjusting the rotation rates of two motors, the car can go straightly or curvedly. Students in the camera group use an upper computer to make a man-machine interaction. It can receive the images and simulate the black line extraction results according to the program written by students. Using this upper computer, participants can easily see the problem of their program and make progress of it.

4.1.5 Common technical points

Although students at the SMU develop different intelligent cars, they indeed share their knowledge and continuously discuss their engineering and design progress. All the students designed their own PCBs for the intelligent car thanks to a few advantages of PCB. Firstly, a PCB can avoid contact problems caused by a broken wire, a weak welded connection and so forth. Secondly, a PCB reduces electromagnetic interference caused by high-frequency signals communication and complicated wire connections. Thirdly, a PCB widens the loop of the same network, making the system easy to release heat. Last but not least, a PCB can fit the car model perfectly.

Regarding the car control algorithm, most students in the lab decide to use a dynamic PID control. Dynamic PID has several advantages. Regarding a dynamic PID, each parameter (P, I, and D) varies with the amount of modification value. Taking direction control as an instance, when the car is running on a straight line, there is no need for the system to change the servo steer angle every time because the modification value on the direct line is relatively small. Changing the angle every time will cause a waste of speed. Therefore, if the modification value is lower than a specific value, the PID parameter remains extremely small to stop the change of servo angle. Conversely, when a car is on a curve, if the parameter P can also increase with the expansion of modification value, it will take less time for a car to go through the curve. Table 2 summarizes the various car designs

4.2 Results

While preparing the competition, participants learnt how to design a voltage-stabilizing circuit and how to make a Pakistan Cricket Board (PCB). Moreover, for the software part, they mastered the application of communication and control algorithm, such as Proportion Integration Differentia-

Fig. 8. Car Model D.

Fig. 9. Car Model E.

tion (PID) control algorithm, fuzzy control algorithm and so on. They also acquired a good understanding of the mechanical structure of the car and motor control by adjusting their cars again and again. Judging from the results, students in this adaptive intelligent car lab have performed quite satisfying grades with the help of the gained knowledge to some degree. Such practical and useful technical knowledge they acquired from the lab will surely be of benefit for their future.

Students of the electromagnetic group studied numerous control methods and design individual controlling strategy for their cars. On the one hand, students from the HaiTian team bond parameters-varying PID control based on fuzzy rules with bang-bang control. To begin with, they added parameters-varying PID control based on fuzzy rules [15] to the control of the steering engine, which means a good try for the young HaiTian team. As illustrated in Fig. 12, the fuzzy controller put error and differential of error together to calculate parameters of PID for the better control of the steering engine. This kind of usage solves the problem that he steering engine meets different PID parameter under all kinds of road conditions. It works quite well and stably.

Besides, the Haitian team drew in bang-bang control on the foundation of incremental PID [16]. The combination achieved better control of the steering engine, enabling participants to detect the rising speed of cars on a straight road susceptibly. On the other hand, the Yu Yang team picked S12 as the only controller, whose processing speed slower. However, S12 is not suitable for fuzzy control. The team went through lots of difficulties, finally find the way out. PID parameters controlling the steering engine vary in a certain quadratic function, based on the difference between the track center and car center, to enable the car to have a better control of direction. In the competition, their car can be quick in straight road with little direction change while be stable in curve road with quick change. Overall this shows great adaptation.

For the camera group, the most important fact is that students participating in the competition should have a prior and clear understanding of the camera sensors. In order to pick the best camera solution, participants should compare the pros and cons of each digital or analogue camera. After selecting the camera, they, then, should learn the working principles of the camera and assistant peripheral circuit to control it precisely. Therefore, while students had a great amount of knowledge on camera sensors, they are more likely to choose a proper camera and build a better interface between the sensor and MCU. Adjusting the car with two wheels to keep its balance during the running process is an additional challenge for every balance group. In order to keep the balance throughout the whole competition, students should firstly know the basic working principles of accelerometer and gyroscope. The next crucial thing for them is to learn how to combine these two components together to lower or even eliminate the noise generated by the slight vibration of the car system. Last but not least, students should insert the balance adjustment function reasonably without interfering with either the

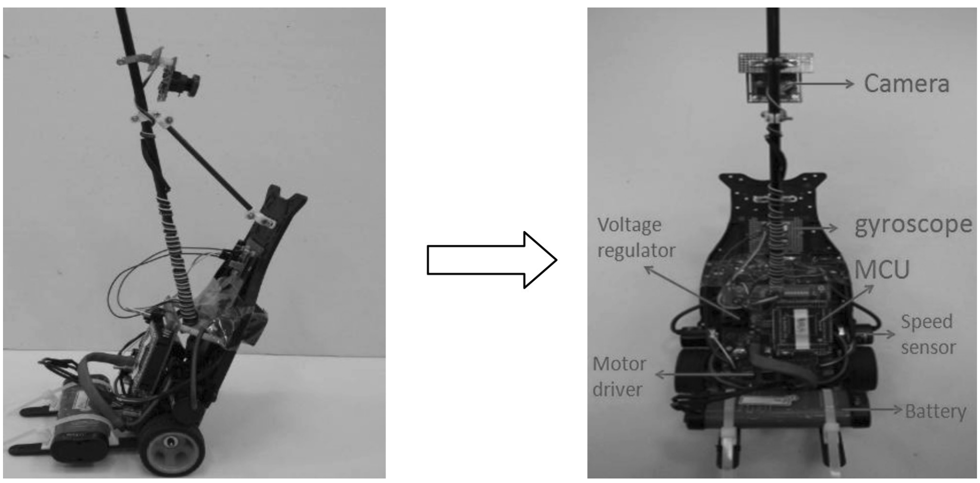

Fig. 10. General appearance of photoelectric car.

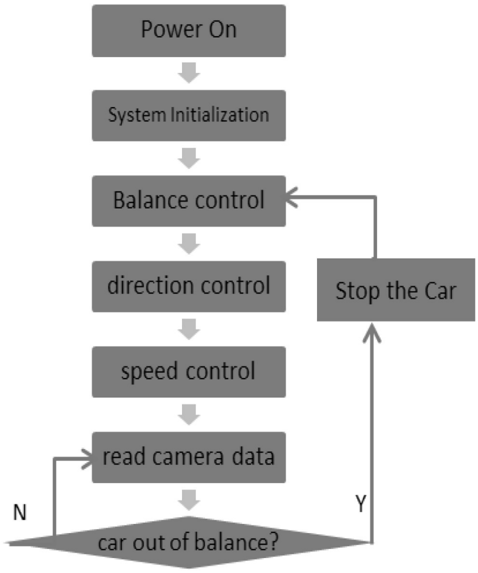

Fig. 11. Flowchart of camera car program.

sensor sampling function or controlling function of the car.

5. Discussion and related work

5.1 Learning outcome

Overall, SMU has participated in the competition six times. A general trend is that students' behaviors and the knowledge gain are pretty impressive. From daily communications between students and teachers as well as from the students' feedbacks after the competition, teachers are pleased to realize that most students show that they have learned much more than expected through the competition. Many students recognized that they did well to carry on rather than give up at the beginning of the whole process. Just as an old saying goes, *it is the first step that is troublesome*. Most new students visit the adaptive intelligent car laboratory with curiosity and interest at first. They think intelligent car is full of fun and show great enthusiasm in doing a car by their own. However, they find out that making an intelligent car is a much more challenging job than their expectations. Consequently, they gradually show less confidence in their own abilities. Some of them even don't think that they can make the car work before the competition and back out. Comparing to the teams entered the lab first, just a minority of them can insist to the end.

During the process, students report that they have suffered a lot when deadline with technical questions. However, the most interesting part of this competition is that the most struggling part is also the funniest part. Indeed, students can meet hundreds of different and even weird questions which can only be solved by themselves during the car-making process. Sometimes, even an extremely simple question can trouble them several days or even weeks. Finding a solution of the question is not easy. In order to overcome these difficulties, students may search many reference books, ask teachers for help, consult online or discuss within the group etc. Even if they are not in a lab, not doing a related work of intelligent car, they keep thinking about the questions. Nevertheless, once students find the answer, they feel they are on top of the world. They feel it is worth spending so much time to solve the problems. By overcoming one question after another, students are not afraid of meeting difficulties any more. Instead, by trying to eliminate the problems, they gain a right thinking pattern to help them think much more logically and efficiently than before.

Additionally, students point out their self-learning abilities has been strengthened tremendously during the process. Since many students do not have a wide range of relevant knowledge and a solid professional foundation, there are a lot of things for them to learn. One student says before she came to the laboratory, she even did not learn anything about the single chip. And so did her team members. Feeling the pressure of lacking essential knowledge, she and her teammates learned great many things about intelligent cars ranging from the working principle of K60, different development platform to designing PCB in ALtium and so on in the first several months by themselves. By the end

Table 2. Summary of the various car designs

Cars	Car Model	Sensor	Control method	Arithmetic	Software
Camera car	Model E Or Model C (two wheels)	Camera	1. Deviation derivation 2.Vertical control 3. Steering control	PID Bang-Bang Fuzzy	1. Microsoft Office 2. Matlab 3. IAR 4. Codewarrior 5. Labview
Photoelectric car	Model B (four wheels, one motor)	Linear-array CCD	1. Deviation derivation 2. Steering control 3. Speed control		
Electromagnetic car	Model C (four wheels, two motors)	Magnetic field sensor			

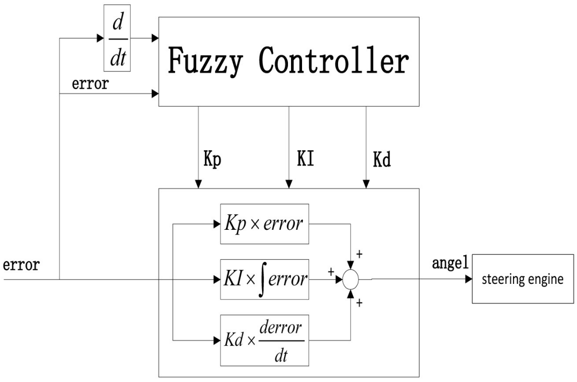

Fig. 12. Parameters-varying PID control based on fuzzy rules.

of the competition, their self-learn abilities have been leveled up a lot. Self-learn ability plays a crucial role not only in a person's school time, but throughout his whole life as well. They have gained benefits from this competition forever.

Moreover, numerous students also say their hand-on abilities have been improved greatly in the lab. During the working process, students are required to solder various circuits such as power supply circuit, signal amplifier circuit using electric soldering iron and solder wires by themselves. Some chips have a lot of pins that can be easily short circuited if they have bad hand-on abilities. Failure is the mother of success. After certain time of practice, students learn the correct method to use electric soldering iron, flux soldering paste and heat guns, and choose a proper soldering temperature etc. to finish a soldering circuit. Hand-on skills is extremely important to engineers. Such kind of skills cannot be obtained in traditional class or without numerous practices. Table 3 summarizes the technological skills acquired by the students during the process.

Regarding the students, and although the acquisition of technological skills is important, probably the most important result relies in the development of hands-on and problem-based knowledge. Students acknowledged that the most valuable achievement is not the final result but the experience gained in the preparation for intelligent car competition. Of course students have also acquired hands-on technological knowledge throughout the whole process but their common feedbacks also show great improvement in group-project capabilities, creativity and the spirit of competition. They often believe that the experience was valuable and provide a useful background for their future. As the competition process is also based on a team, students also learn to behave in group. Since the creation of the laboratory, there have been more than 20 students from our lab that went to well-known academic institutions for further study. Moreover, some of the students started their working life in international companies thanks to their abilities and performance in the competition. It appears in many cases that they can adapt to their new jobs quickly with good hands-on and learning abilities. Moreover, a lot of companies have no hesitation in hiring students as long as they are from our lab. Last but not least, students from diverse majors meet in the lab and share time together for one or more years. Usually, three students form a group. They share their joys and sorrows and learn from each other in the process. By working together, they learn to be cooperative. By sharing their viewpoints, they practice their expressing skills. These social skills are essential when a person is facing a job market. The laboratory is like a small society. Students gradually cultivate these social skills unconsciously. One of the students even became an expert on intelligent car after doing it for three years. He is the leader of the intelligent car lab and is responsible of buying equipments and elements. He is also willing to devote his time helping new students. Several students understand quickly under his cultivation and become the potential leaders of the lab after his graduation. In conclusion, students gain a great number of useful abilities and skills such as thinking ability, self-learn ability, hand-on skill, cooperative spirits and so forth. These valuable qualities and abilities will keep helping them to be more competitive after their graduations.

5.2 Related work

Innovation is an important standard to measure university undergraduate students' abilities. A subject-driven competition is an effective way to compare and improve university students' performance [17]. Similar to smart car competition, there are a lot of undergraduate competitions which having a very good role in improving student's overall technical performance and understanding of engineering issues. One example is the Intel Cup Undergraduate Embedded System Electronic Design Contest. This competition gives undergraduates a chance to improve their creativity and learn team-work. It is also helpful in prompting embedded education and keeps embedded education close to the industry [18]. The competition also aims to foster innovation skills amongst students in the disciplines of Information Technology and Electronics, but the scope is much larger and oriented to the design of any device that could be used in a real-world application, such as in the home, automobile, medical, industrial, or other industries. Besides, Mobile Robot Competition forms a valuable tool for academic institutions in directing their research and scholarly endeavors [19]. As for civil engineering students, structural design competitions not only improve their comprehensive professional skills but also their creative capacity, practical ability and collaborative ability. Moreover, it is a significant platform for civil engineering students to train their creative and practical capacities [20]. All of these competitions are aiming for cultivating students' ability. Combined with classroom education, these competitions can help students improve themselves quickly and roundly. Despite the fact that these competitions are relatively related to our work, they have been so far and to the best of our knowledge not fully reported in education engineering journals.

6. Conclusion

The adaptive car lab introduced in this paper develops a proactive engineering environment for undergraduate students. Not only the framework provides an interactive hands-on learning environment, but the competition objective also generated a proactive environment that often lead students to surpass their initial capabilities throughout the whole process. The environment developed includes several components that are important for any engineering career: mechanical, electronic and computing skills, but also group-learning and group organization, working under pressure in a competitive environment, and creativity. These are amongst the assets developed during the course that can be also considered as a long-term learning process and not as an immediate learning objective as in many teaching programs. The proactive laboratory provides an open platform for them to try and practice new experiments freely. Finally, students will know clearly what should be learned and learn it willingly. Many of them fall in love with their majors and seek further study in that domain.

Although there are numerous advantages in the adaptive intelligent car laboratory, teaching staff at the SMU still have several issues to work on. Firstly, most SMU students only participate in one Freescale competition and then graduate. This causes a break of knowledge and experience inheritance between young and old students. Therefore, young and new students usually have to spare a lot of time learning everything from the very beginning. If new students can start on the basic of past experience, they will have more time to test and improve their cars. Accordingly, they are more likely to make breakthroughs in the competition. Ideas are worth spreading. Teaching staff at the SMU expect a mutual progress by sharing teaching experience in this adaptive intelligent car laboratory with other universities and institutes. That is one of the important reasons why this essay is written. The Freescale intelligent car competition also provides a good platform to communicate. By comparing the competition results, teachers and students can know clearly whether their intelligent cars are good or bad. By observing intelligent cars made by opponents, students can get new ideas on how to improve their cars. Judging from past competition results, it is worthwhile to remark that students have made great progress on intelligent car's making and control. Such cheerful results are gained thanks to frequent idea exchange and fierce competitions.

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References

1. M. Daniels, A. S. Cajander, A. Pears and T. Clear, Engineering education research in practice: evolving use of open ended group projects as a pedagogical strategy for developing skills in global collaboration, *International Journal of Engineering Education*, **26**(4), 2010, pp. 795–806.
2. K. Buch, C. Sena, K. Buch and C. Sena, Accommodating diverse learning styles in the design and delivery of on-line learning experiences, *International Journal of Engineering Education*, **17**(1), 2001, pp. 93–98.
3. A. Elshorbagy and D. Schönwetter, Engineer morphing: Bridging the gap between classroom teaching and the engineering profession, *International Journal of Engineering Education*, **18**(3), pp. 2002, 295–300.
4. A. Daz Lantada, A. Hernandez Bayo and J. de Juanes, Promotion of professional skills in engineering education: Strategies and challenges, *International Journal of Engineering Education*, **30**(6B), 2014, pp. 1525–1538.
5. C. Zhou and J. Shi, A cross-cultural perspective to creativity in engineering education in Problem-Based Learning (PBL) between Denmark and China, *International Journal of Engineering Education*, **31**(1A), 2015, pp. 12–22.
6. I. De Los Ros-Carmenado, F. Rodriguez Lopez and C. Perez

Table 3. Summary of the technology and skills students mastered during the process

Learning Subject	Technical Details
MCU technology	C language, GPIO, AD, PWM, PIT, Counter, SCI, SPI, DMA
Hardware technology	1. DC-DC converter 2. Motor driver circuit 3. Operational amplifier circuit 4. Skills in making PCB
Simple technology in machinery	Axle-pin rake, Toe-in, Four-wheel alignment
Control algorithm	PID, Bang-Bang control algorithm, Fuzzy
Quality aspect	Improvement in concentration, patience, learning and hands-on abilities. Students with these abilities are better at overcoming difficulties.

Garca, Promoting professional project management skills in engineering Higher Education: Project-Based Learning (PBL) strategy, *International Journal of Engineering Education*, **31**(1B), 2015, pp. 184–198.
7. 9th National University Student Freescale Intelligent Car Competition Regulations and Disciplines, 2014, pp. 3–4.
8. M. Zeinali, I. Z. M. Darus and A. H. Taghavi, Effect of front double wishbone strut position on vehicle steering and suspension performance, *Proceedings of the IEEE Conference on Control, Systems and Industrial Informatics (ICCSII)*, 2012, pp. 151–154.
9. M. J. Neath, A. K. Swain, U. K. Madawala and D. J. Thrimawithana, An optimal PID controller for a bidirectional inductive power transfer system using multiobjective genetic algorithm, *IEEE Transactions on Power Electronics*, 2014, pp. 1523–1531.
10. Q. Yuan, Y. Zhang, H. Wu and H. Wang, Fuzzy control research in the courses of smart car. machine vision and human-machine interface (MVHI), *Proceedings of the International Conference on Machine Vision and Human-machine Interface*, 2010, pp. 764–767.
11. H. Kim, J. Kim, M. Shim, J. Jung, S. Park and C. Kim, A digitally controlled DC-DC buck converter with bang-bang control, in proceedings of the International Conference on Electronics, Information and Communications (ICEIC), 2014, pp. 1–2.
12. V. Parra-Vega, S. Arimoto, Y. H. Liu, G. Hirzinger and P. Akella, Dynamic sliding PID control for tracking of robot manipulators: theory and experiments, *IEEE Transactions on Robotics and Automation*, 2003, pp. 967–976.
13. W. Liu, Hardward design of smart car based on mc9s12xs128 microcomputer, Electronic Design Engineering, 2010, pp. 102–103.
14. J. Tao, X. Wang, T. H. Zhang, Y. H. Tan and H. X. Sun, Design and implementation of humanoid robot based on mk60 embedded microprocessor, *Applied Mechanics and Materials*, pp. 687–691.
15. N. Wahid, and N. Hassan, Self-tuning fuzzy PID controller design for aircraft pitch control, *Proceedings of the Third International Conference on Intelligent Systems Modelling and Simulation*, 2012, pp. 19–24.
16. Z. Xu, J. Wei, J. Li and Q. Zhou, Design of a temperature control system using incremental PID algorithm for a special homemade shortwave infrared spatial remote sensor based on FPGA, SPIE 7853, *Advanced Sensor Systems and Applications IV*, 2010, pp. 78531G-78531G-6.
17. S. D. Zhao, Y. X. Zhou and Y. S. Chen, Analysis of subject competition and innovative training based on national university "the freescale cup" intelligent car competition, Laboratory Science, 2011, pp. 4–6.
18. T. Chen, J. Wang, B. Xie and G. Xu, The organization of Intel Cup Undergraduate Embedded System Electronic Design Contest, *Proceedings of the 14th IEEE International Conference on Parallel and Distributed Systems*, 2008, pp. 751–756.
19. J. Green and S. Plumb, Mobile robot competition, IEEE Africon 2011—The Falls Resort and Conference Centre, Livingstone, Zambia, 2011, pp. 1–6.
20. C. Jia, C. Zhang, L. I. Yingmin, P. Yang, H. U. Ying and J. Han, On the importance of structural design competition to civil engineering undergraduate education, *Journal of Architectural Education in Institutions of Higher Learning*, 2014, pp. 133–135.

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