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Educational framework for automotive ECU design: A Case study

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Abstract : The development of automotive sub systems involves integration of multiple sub modules. Each sub system involves more than one subcomponent, with possible dependencies between components. The electronic sub systems, usually known as electronic control units(ECUs) are the integrated parts of modern automotives. The development of such modules requires the knowledge belonging to diverse engineering domains and also an ability to work in multidisciplinary environment. This paper discusses about an activity attempted for the course on automotive electronics for the third year engineering students of circuit branches. The activity involves providing an experience of development of ECUs which in turn provides an opportunity of getting exposed to industrial environment. An automotive electronics, a core course taught for the students of circuit branches is mainly application oriented involving system level concepts. The course was introduced to cater to the needs of automotive industries. The concepts of entire course can be divided into five main domains; power train, safety systems, body, driver assistance and infotainment systems. Accordingly to complement the learning it was decided to introduce an extended activity in the form of course projects wherein the theme was to develop electronic control units (ECUs) for every domain. An ECU of an automotive has multiple functionalities, each representing a sub-module of a bigger system. The integration of sub-modules to realize a specific ECU was major objective of the activity. The sub-module development involves modelling, hardware/software development and communication protocol implantation. To impart the industry like working culture amongst students, every sub-module belonging to specific ECU was assigned to the students of different department. Sub modules were developed independently by specialized dedicated team of a particular department and were integrated to demonstrate a final ECU by different department teams. The Prototype models with an option of testing on a test vehicle were the results of this activity. The student learning was measured in terms of their ability to work in a team, project management skills and their technical competencies to develop sub-modules and integration of sub modules. The outcomes are also discussed with respect to students placements in automotive industries and attainment of ABET outcomes.

Key words : Automotive electronics, sub module, integration, ECU design

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1. Introduction

The automotive industry is one of the fastest growing industries across the world. The every new functionality introduced in a car is having a significant contribution from the field of electronics and related software. Latest trend in automotive sector is towards autonomous vehicle or driverless vehicle wherein the entire vehicle is controlled by electronics and its related intelligence. When we look at the total price of the car, in today's high-end vehicle around 30-35% of the cost is for electronics and software. The automotives are no longer mechanical systems; instead along with mechanical systems, the contribution of electronics and computers is huge. So, nowadays automotive industries are looking for skilled engineers belonging to electronics and computers domain. These trends have motivated us to introduce automotive electronics at our organization [1].

The course being highly interdisciplinary in nature requires the competencies related mechanical systems, control systems, electronics and software engineering. The course mainly deals with development of embedded systems involving hardware and related software to realize various functionalities. The framing of course contents was challenging because of its multidisciplinary nature. The leading automotive industries like Robert Bosch and KPIT came forward for collaborating and contributed at various levels of designing and delivering this course [8]. The course was designed in collaboration with these automotive industries and also taking the inputs form experts belonging to mechanical, electronics and computers disciplines. The course contents were so framed that, the students undergoing through these courses can directly be put on job after joining the industry [2]. The contents were including the topics related to current status of automotive industry, domain knowledge of mechanical systems, control systems, embedded systems, diagnostics and also the topics related to model based development which is the latest trend in automotive industry along with software development and its standards.

The theoretical concepts were also augmented with laboratory exposure. The laboratory contents were framed systematically, so that students get exposure to hands on experience at different levels. The laboratory included demonstration of cut sections of automotive mechanical systems, GUI controlled engine control system, experiments on modelling and simulation, model based development using Simulink, embedded C coded sub module development and on communication protocols. The laboratory sessions provided the necessary hands-on experience on the theoretical concepts learnt.

The course was introduced at the sixth semester level, for all the circuit branches involving Instrumentation Technology, Electronics and Communication Engineering and Electrical and Electronics Engineering wherein the student had a necessary background of embedded systems development, design of electronics systems, basics of programming and mechanical systems.

Along with the classroom teaching and laboratory exercises, various other active learning methods are practiced to enhance the learning of the students. These methods included, expert lectures by industries to introduce students to the current technology related issues of industries, animations and video presentations to make the concepts clearer.

Further, enhance the learning and to prepare students industry ready, the course project concept was introduced. The paper discusses the methodology and implementation details of course projects for the course automotive electronics. The course is of three credits with two minor exams, semester end exam and course project. The questions of minor and semester end exams are framed to test the learning levels of students according to the blooms taxonomy [5]. The course along with the delivery and evaluation methods addresses both the technical and professional outcomes of the program.

Organization of the paper is as follows section II deals with design of course of course projects, section III Implementation methods of course projects, section IV deals with evaluation methods , their effectiveness and discussion and section VI with Conclusion.

2. Course Project Design

Background survey: What Automotive Industries expecting from an Automotive Engineer? The survey related to requirements from automotive industries from an automotive engineer indicated that, along with the domain knowledge, competencies in programming, tools usage and knowledge about the current industry standards were expected. Below Fig. 1. is the snap shot of one such requirement.

```
Sr. Engineer (Embedded C)

* Worked in Steering/Power train/Brakes/Transmission domain.
* Strong development experience in embedded C
* Strong development experience in CAN/Flexray,UDS/KWP , SPI communication protocols
* Strong development and modeling experience in MATLAB, Simulink, and Targetlink tools.
* Strong debugging skills
* Worked with ISO14229,ISO TP
* Strong knowledge in tools like CANalyser/CANoe, CANDiva,CANstress,CANDELA
studio,Lauterbach

B.E(ECE/EEE/CS)

3 - 6 Years
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Fig.1 Expectations from an automotive industry

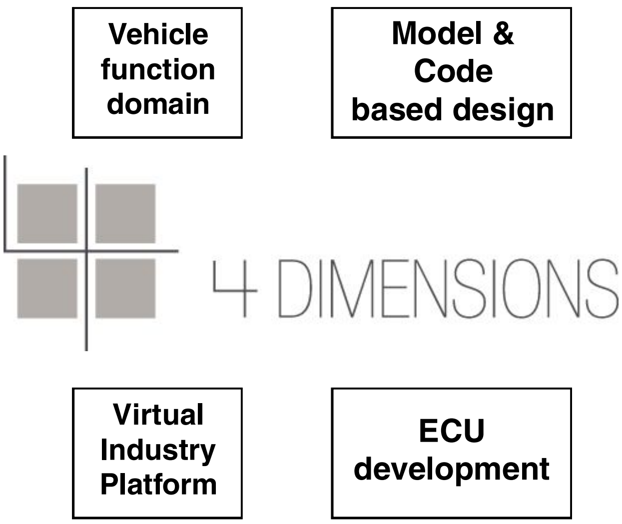

Fig.2 Four dimensions of course projects

The course on automotive electronics was introduced with the intention of incorporating industry specific skills amongst the students. The automotive industry is broadly classified into two segments, car makers or original equipment manufacturers and suppliers. Usually OEMs provide the requirements and accordingly suppliers provide the sub-modules to car manufacturers. OEMs in turn integrate the sub modules, obtained by different suppliers to produce car. There are going to be lots of challenges during integration because of compatibility issues related to hardware and software of different suppliers. To illustrate these kinds of scenarios to students, we have chosen course project implementation as an extended activity to the course. Through course projects we have tried to introduce industry working environment to the students. The course projects were designed in such a way that every problem statement had a sub problem associated with it. Students had to integrate the sub module to realize the final prototype product.

The entire design process of the activity had four dimensions as depicted in Fig 2. i) Vehicle function domains ii) Model based design iii) Virtual industry platform & iv) ECU design.

Vehicle function domains gave the students exposure related to automotive embedded concepts. Model based design is a latest trend in automotive design, wherein functionality is delivered in the form of software rather than hardware. Virtual industry platform is an attempt made to give students an exposure about real world industry environment. ECU design was a theme of the activity, wherein they have to develop a sub module related to automotive embedded system[7].

The course project structure is depicted in the following Fig.3.

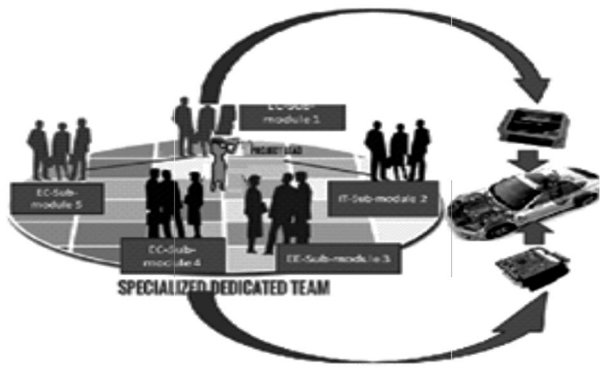

Fig 3: Course project structure

The course projects had broader theme of "ECU development", wherein the objective was to develop sub modules, integrate modules to realize ECU and implement on a test vehicle. The problem areas were precisely defined and they belonged to different domains of an automotive. The areas were,

Areas:

Engine Control- Injection /Ignition, EGR control, Secondary air injection system, Solar/Hybrid, Knock measurement and control, I3S

Safety Systems-Hill hold, Hill descend control, cruise control, Brake disc wiping, brake boost assist, vehicle dynamics control

Body domain applications- Wiper control, power windows, interior lighting control, advanced head lamp control, seat belt control, LIN powered door/window, Wiper control, Vehicle environment monitoring system

ADAS: Seat belt detection using image processing, face detection for vehicle security, obstacle detection using image processing, drowsiness detection, lane detection, pedestrian detection, traffic signal detection, over limit height bar detection, front end collision avoidance using image processing.

As shown in Fig 3, there were four to five sub modules associated with one problem. To enhance team working culture of the students, every sub problem was assigned to the students of different program. Every team was assigned one sub problem and each team has to integrate their module with other modules which are developed by other team belonging to different program. For every problem statement one manage was selected, his role was to coordinate the entire group activity. While developing the sub module, each team has to perform the following tasks, which gave the students entire project development experience.

The tasks included,

Developing the mathematical model and building it using MATLAB/SIMULINK

Realizing the module in embedded environment using suitable CPU, sensors/actuators and related electronics.-Embedded H/w

Embedded software

Communication Protocol implementation: Providing CAN interface and analysis using CANalyzer

Integration of sub-modules on a common platform

3. Implementation Methods

One of the main challenges of the automotive industry is to come up with methods and tools to facilitate the integration of different electronic subsystems coming from various suppliers into the vehicle's global electronic architecture[2]. The introduction of course projects and practicing this activity by creating industry like environment helped the students to experience the industrial work culture.

The different phases of project realization are discussed below,

3.1Identifying the automotive domains and assigning problems: The automotive industry being very huge and the sixth largest economy in the world require the qualified employees having multidisciplinary skills. The automotive domains are very vast with Carmakers distinguishing these domains for embedded electronics in a car and are broadly classified as power train, chassis, body, communications and driver assistance systems. The problem statements were framed based on these domains[3]. Every domain has scope for design, development and innovation. The example problem statements are discussed below,

Power train domain: The power train domain mainly deals with the components which are responsible for vehicle's longitudinal propulsion. Generation of power which is realized through engine and also transmission of power, i.e. transmission systems. This domain represents the systems which control the engine power generation according to driver's request. The purpose is to optimize the parameters like fuel efficiency, engine rpm and exhaust emissions. Fig 4 represents power train domain and related case studies.

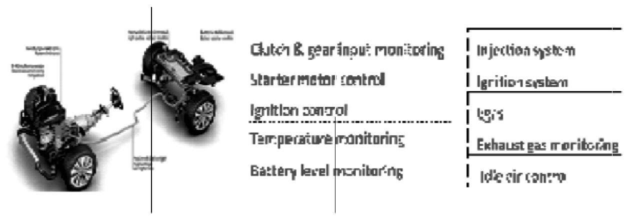

Fig 4. Power train domain and related case studies

Chassis domain: The chassis domain refers to the four wheels and their relative position and movement; in this domain, the systems are mainly steering and braking. The chassis domain consists of systems whose aim is to control the interaction of the vehicle with the road. The Controllers take the requests from driver in the form of steering, braking or speed variations, based on environmental conditions and road profiles the decisions are taken. Systems like antilock brake systems (ABS), electronic stability program (ESP), automatic stability control(ACS) and all-wheel drive(4WD) are the systems belonging to this domain. The systems here are classified as active and passive safety systems. Fig. 5 shows example problem statements given to students.

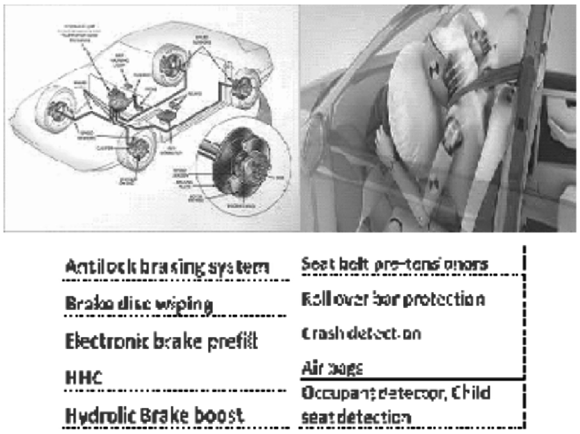

Fig 5. Safety systems & related case studies

Body domain: The body domain includes the entities that do not belong to the vehicle dynamics, thus being those that support the car's user, such as wiper, lighting, window lifter, air conditioning, seat equipment, etc. The problem statements given reflecting this domain are shown in Fig. 6.

Fig. 6 Body domain and its case studies

Advance driver assistance systems (ADAS): The concept of autonomous vehicles is the future trend in automotive domain. The driver assistance systems are step towards autonomous vehicles. The driver assistance systems and related case studies are shown in Fig 7

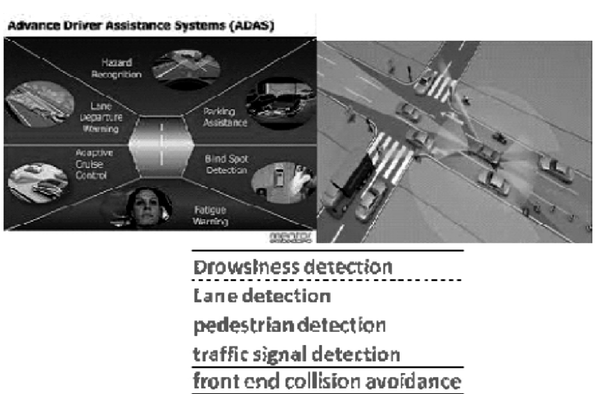

Fig. 7 ADAS and related case studies

3.2 Implementation of Automotive communication protocols: ECU is incomplete without providing the necessary communication. It was made mandatory that every sub module developed must have implementation of communication protocol. The automotive communication usually includes CAN, LIN, Flexray & MOST protocols as shown in Fig 8. This has led to the concept of multiplexing, whose principal advantage is a significant reduction in the wiring cost as well as the flexibility it gives to designers.[4]

CAN is the commonly used communication protocol. Every sub module along with hardware and software development had implemented CAN communication.

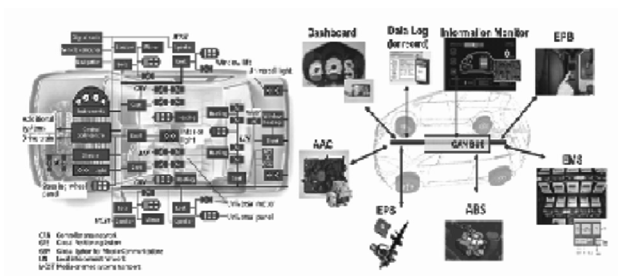

Fig 8 Automotive communication protocols and CANalyzer set up

CANalyzer from Vector, is the most commonly used CAN analysis & simulation tool in automotive industries. The exposure to this tool gives an added advantage to the students seeking employment in automotive industries. Every team implemented CAN communication to their sub module and also did the analysis using CANalyzer.

3.3 Sub module development and integration

The sub module development included various design steps. It was made compulsory that every team goes through all the steps before final prototype implementation. The steps were reflecting the ECU development stages the way it exists in the industries. The description of the sub module development steps are given below,

i) Mathematical modelling and simulation: Model based development is the latest trend in automotive industries. Every module was first described mathematically and the behaviour was tested for all conditions using MALAB/Simulink.

ii) Development of embedded hardware: Once the team was convinced with simulation, the next step was to start with the hardware implementation. Students decided with the hardware components by discussing with the other team members belonging to same group. This was essential as their module after completion has to be integrated with other modules. There were compatibility and portability issues to be addressed. The hardware was built using sensors, actuators, related electronics and microcontroller. The model based approach was used for initial testing of their hardware, wherein the simulink models were ported to the hardware like arduino, raspberry pi etc. Once their module was found working satisfactory, then the next step was to write the embedded C code.

iii) Development of software: After hardware was tested using model based development, the next step was to write the efficient embedded C code. The software was developed using suitable IDE following software engineering approach. The code to realize the desired functionality and also to provide the necessary communication was written.

iv) Providing CAN interface and analysis using CANalyzer: The CAN interface was provided to exchange the information between modules. Based on the problem statement and integration the information to be exchanged, the size of the information, the priority and arbitration was decided. Every component of communication was tested using CANalyzer.

v) Integration of sub modules: Once the the sub module was ready, now it was the time to integrate the modules. The challenges like portability issues, re use of components were face by the students and after integration the prototype system was tested for different test conditions. Below Fig. 9 shows a snapshot of one such activity, the problem statement was related to ECU for safety systems. The ECU had multiple functionalities like seat belt warning system, speed control system, crash avoidance system and air bag deployment upon crash. All the sub functionalities were developed by individual teams and finally integrated on a common ECU. All the sub modules exchanged the information over CAN communication protocol and the analysis of information was done using CANalyzer. Teams belonging to IT,EC and EEE were participated in this activity.

Fig 9 Course project demonstration

A. Assessment Methods

Regular reviews were conducted to monitor the progress of each team and entire group. There were three reviews assessing different attributes. The review team was consisting of faculty from the circuit branches and mechanical streams

Review 1: Survey & Requirement analysis, Integration plan & Roadmap (Conducted during second week of their project start)

During this review every team has done the survey on problem statement given and sub problem assigned to them. Integration plan of their group and also the roadmap for executing the plan was reviewed. This review had a weitage of 30% of the total marks.

Review 2: Mathematical Model (MATLAB/ SIMULINK model), Hardware /Software co-design review (conducted on fourth week of their project start) [9]

This review was crucial as the mathematical model, hardware & software selection was reviewed. The selection of sensors, actuators, microcontrollers, programming language and the selection of communication protocols and compatibility and portability issues amongst the teams was also assessed. This review had a weitage of 40% of the total marks. The review team was continued with earlier committee.

Review 3: Integration demo: The last review was integrated prototype module review, wherein the students were assessed for prototype ECU working, interoperability, integration extent and its complexity, contribution of individual team and also presentation skills. The review was conducted by internal faculty and also by industry experts. The review had a weitage of 30% of total marks.

B. Outcomes of The Activity

The course project activity provided an opportunity to achieve both technical and professional outcomes of ABET. The table 1 below shows the activity phases mapped to outcome elements& Pos, the fig. 8 shows the PO attainment addressing outcomes a, c,g,i&k

Reflections of course project with continuous monitoring and feedback

The activity was practiced by all the students of Instrumentation Technology, Electronics and communication engineering and electrical and

Activity Phases	Outcome elements	ABET Program outcomes addressed
Literature survey and problem definition	An ability to identify needs. An ability to formulate problem An ability to find alternate solutions and choose the best one. Ability to work effectively in project teams, both as a member and leader, with different skills.	c, d, i, j
Concept level design	Understand environmental, political, economical, aesthetics and social impacts of engineering work. An ability to use established method to design a system/process. Knowledge of contemporary issues in the field of Instrumentation Technology	c, j
Implementation	An ability to use modern engineering tools for modeling and simulation Ability to engage in independent and life-long learning in the broadest context of technological changes	i,k
Demonstration & report writing	Oral and visual communication skills appropriate to the profession of engineering	g

Tab 1. Activity outcomes mapping to program outcomes

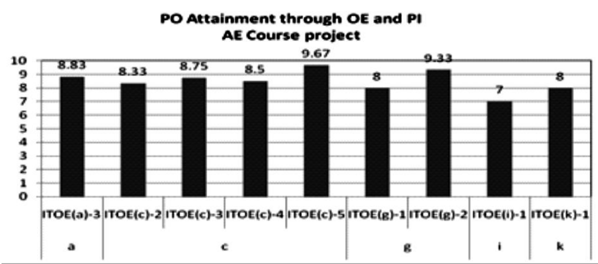

Fig. 7 PO attainment

electronics engineering students. With this activity, different teams were able carry out course projects addressing different themes. Around 50 different projects with different themes were carried out. This activity resulted in building strong knowledge of fundamentals, realizing the various aspects engineering analysis and hence the problem solving ability of the student enhanced [5]. The students' exposure to industry like environment is expected to help them in their carrier endeavours. Finally the assessment based on student feedback has been collected by each team as detailed in the appendix and the statistics shows that the objectives of the course project were satisfactorily met as mentioned in Fig. 5. Question 1 and 3 related to understanding of concepts and applying the same to the application has made an impact on learning. Question 2 relating to scope of understanding beyond curriculum is satisfactory. Suggestions by review committee and participation in technical events reflected in question 4 and 5 needs a scope for improvement.

Reflections of activity in participation in technical events and placement activities:

The activity resulted in students participating in various technical events. Students exhibited their projects at various competitions like Bosch inscribe, KPIT sparkle, TATA motors mind rovers and ARM tech symposia and also have won the top prizes.

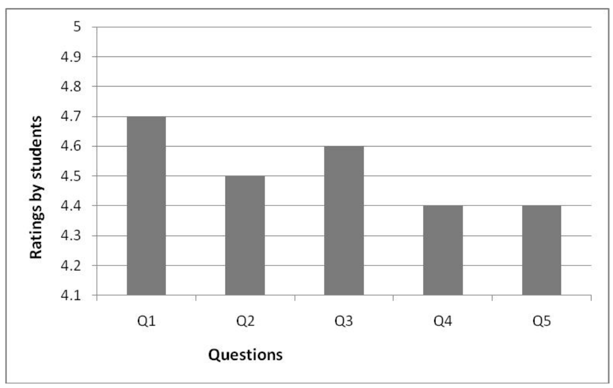

Fig. 5 Feedback questionnaire response

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Reflection of the activity in student placement

The student placement in automotive industries like Bosch, KPIT, Delphi and Continental has considerably increased. The Fig 8. Shows enhancement in student placement for the last three years after the introduction of course on Automotive electronics.

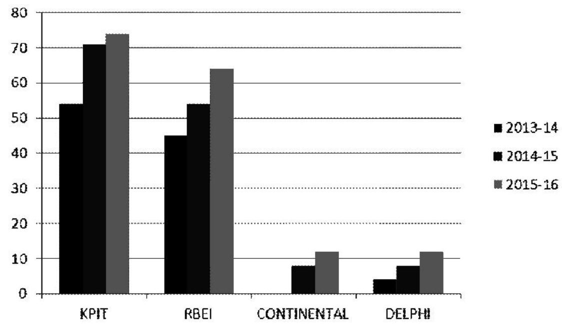

Fig. 8 Student placements in Automotive companies.

4. Conclusion

The activity involved development and integration of sub modules to realize an automotive ECU. The entire design development phases of the activity were replicating the industry like environment. The activity exposed the students to industry work culture. The reuse of components, sub module development and interface was experienced by the students. Over all attainment of ABET outcomes and student placement in automotive companies was convincing, students and industries have given a very good feedback for the activity. .

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Appendix

The questionnaire consists of five questions, the students are asked rate on a scale of 1-5.

1. Does the course project helped in understanding the automotive systems better?

2. Did the course project boost your knowledge in the area of Automotive Domain?

3. Are you able to apply your knowledge of Instrumentation and control in Real time Embedded Automotive applications?

4. Did the Review committee give you the right feedback to guide you for the implementation course project?

5. Did the course project help you to participate in technical events and placement activities?