Assessing the Use of Open Source Microcontroller Board for Teaching Engine Sensing and Communication in Automotive Laboratory

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***Abstract*—Open source microcontroller (MCU) boards have made significant inroads towards classroom teaching over the last decade. Many programs have already switched from the traditional educational boards to, for example Arduino products, due to their low costs, easy to use, flexibility, and wide adoption in both consumer and industrial applications. However, comparing with their commercial counterparts, open source boards still lack rigorous and well-designed teaching, especially lab materials to have a seamless integration with existing curricular. Engine systems and controls is a core course in automotive engineering (AET) program that teaches students the theory and application of on-board diagnostics and monitoring system. The course has an intense lab component. Despite the consensus that AET curriculum needs more mechatronics material to reflect the critical roles that electrical, electronics, computing, communications, controls and software technologies play in today's vehicles, we find that nationwide, the lab facility of automotive programs are still heavily mechanical. We believe open source MCU boards are the ideal tool to develop new educational equipment and materials to transform automotive labs and to bridge the gap between classroom and industry knowledge base. In this work-in-progress paper we first introduce the Arduino shields for engine sensing and communication that we have designed at the request of, and in collaboration with AET faculty. We then present the assessment plan to evaluate the boards' effectiveness in helping students understand fundamental mechatronics concepts and practices, and their impact on students' learning experience for engineering design in a multi-disciplinary team.**

I. Introduction

Engineering education is undergoing major shifts to both accommodate the challenges it faces and also to embrace the unprecedented opportunities. In [1], Froyd et al. argue five major shifts in 100 years of engineering education. Some of them are in progress, and the way they are shaping engineering students' knowledge and skill set is still evolving. One of the trends shows a renewed focus on design as the major and distinctive element of engineering education. In particular, more and more schools are interested in design teams to be comprised of students from different programs. The advantages of this composition is obvious, however for the practice to come to fruition, one main issue is to find proper problems or projects where student talent and knowledge can best mesh and produce.

One area that a multidisciplinary team can easily find common interest is automotive control. There are several reasons. First, a joint team of automotive and electrical students can help each other gain fundamental knowledge and experience in vehicle electronics and computer systems, which play the key role of driving the vision for ideal automobiles in a sustainable future. Automotive students would arguably benefit from the partnership the most because the experience can lead to better understanding of "the application of computers in analysis, design, manufacturing, and operation of facilities" required by ABET. Second, despite the consensus that automotive engineering technology (AET) curriculum needs more mechatronics materials both in theory and experiential learning, they have yet been systematically integrated into core AET courses, and the lab facility and hardware are still heavily mechanical. Consequently, there exist many student projects with various scales of complexities that could lead to new materials to complement and enhance existing lab content, and help improve teaching eectiveness and course delivery.

Another trend identified by Froyd et al. [1] is that technologies have been predicted to transform education. This is not just limited to the wide adoptions of computers and other information technologies in classrooms, but also the reality of many products, especially electronics and computer equipment, have entered previously uncharted territories and significantly improved productivity and creativity. The prime example is that today, nothing has been more pervasive in everyday products and changed our daily lives more than microcontroller. Learning the applications of microcontroller has thus become a necessity to many non-electrical or computer students. This development has presented educators a pressing task of introducing microcontroller in curricular that historically have little or zero exposure of the subject.

The traditional educational microcontroller boards are built around commercial chips from vendors such as Intel or Motorola. However, open-source microcontrollers like Arduino have gained tremendous popularity recently. They are no

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longer deemed as just for hobby, but have found their way into classrooms at all levels. For higher education, more engineering programs have embraced Arduino as a valuable teaching aid in their own fields. For example, Riofrio and Northrup [2] use Arduino in teaching introductory mechatronics course for mechanical engineering students. Similarly, an Arduino kit for learning mechatronics and its scalability is introduced in [3]. In [4], students work in teams to construct a compressed-air motor with Arduino controlling inlet air pressure. Butterfield and Branch [5] report the success of using Arduino and Matlab in chemical engineering freshman design laboratory. In [6], the authors demonstrate an online transfer engineering curriculum that uses Matlab and Arduino to cover a broad range of fundamental and engaging topics and projects including electronics, basic test equipment, programming. In [7], Arduino is used to produce a low-cost and flexible inverted pendulum for feedback control lab course. Arduino is presented as a platform for programming, design and measurement in a freshman engineering course in [8], and sophomore autonomous robot [9]. Lilly et al. [10] use Arduino to design a direct-injection six-cylinder radial compressed air motor in an introductory mechanical engineering course. Many mainstream computer science or computer engineering programs have also started to adopt open source platform [11]. Arduino has even been extended to non engineering curriculum, as shown in [12], for intelligent systems development. However, our research has shown that very limited attempt has been made to use Arduino to revamp automotive engineering technology lab and courses, which as pointed out early, need vehicle mechatronics materials to reflect the industry status quo.

In this paper, we report preliminary results on a National Science Foundation supported project to develop customized microcontroller (MCU) boards accompanied with a suite of lab modules to engage students through MCU-based, engine-targeted measurements, communications and controls. To this end, we assemble a team that consists of faculty and students from AET, computer engineering technology (CET), and mechanical engineering technology (MET). The project and its assessment data can provide future reference on how a multi-disciplinary team can help enhance students' learning experience in engineering design.

II. Methods

To better serve AET students, we focus development effort on addressing lab needs in engine-related courses, in particular Engine Systems and Controls, which is a core in AET curriculum that teaches the theory and applications of on-board diagnostics and monitoring system. Engine plays the central role in automotive mechanical system. Consequently the microcontroller of engine control unit (ECU) boasts the highest computing power among all electronics in a car. In order for engine to function normally, the ECU needs to constantly monitor and control many engine parameters in real-time. Studying engine control can naturally draw interests from students from AET, MET and CET students. Unfortunately, commercial engines have their sensors contained in the housing, which make them difficult to access. In order for AET students to observe the sensors in action, we must devise a plan to work with engine sensors externally but still rely on engine's mechanical power to react. For this purpose, we resort to a technique called sensor manipulation.

Sensor manipulation has been shown to be an effective method in both engine testing and development [13, 14]. It is often used to investigate fuel delivery, spark timing, boost pressure, top speed, redline, or other factors. Using the Arduino microcontroller board with customized shield as the signal conditioning (SC) circuitry, we have developed the sensor manipulation device along with a suite of lab modules to help the automotive students connect classroom learning with real-world problem solving.

The key for sensor manipulation is to create a false virtual reality around the ECU [15]. To achieve this, our board is designed to be an input interceptor. As shown in Figure 1, instead of letting engine connect directly to the ECU, we re-wire the cables to lead the engine sensor readings to the customized microcontroller board. A graphical user interface (GUI) that runs on a host PC displays the conditioned engine sensor signals out of the Arduino/shield combination. Not only the students can visualize the engine dynamics through various graphing tools in GUI, more importantly, they are allowed to change the sensory data to strategically "lie" to ECU about the status of one or more engine sensors under certain conditions in such a way that the ECU's standard logic provides modified engine management.

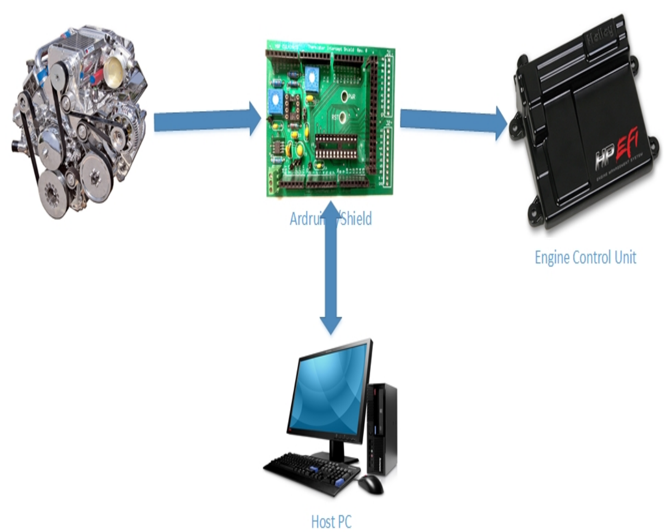

Fig. 1. Sensor Manipulation Through Arduino/Shield

We decide to use Arduino board as our base platform. Using Arduino/shield is a novel approach because it offers greater flexibility and adaptability for both project development and dissemination comparing with existing methods. First, Arduino's open-source concept allows the boards to be quickly adopted by interested peers or even modified to suit their specific needs. Second, the shield is ideal to accommodating the need of manipulating multiple sensors: each sensor has its own signal conditioning shield; there is no need to alter the Arduino main board; and multiple shields can be stacked to allow different sensors to be processed simultaneously.

Another advantage of using Arduino is that it is well supported by its own library and third-party software, which makes developing front-end user-friendly GUI very easy. National Instruments' LabVIEW, the industry standard for graphical programming, has interface for Arduino. The use of LabVIEW with Arduino in the design of a curriculum-spanning mechanical engineering laboratory has been proven successful by Dillon et al. [16]. In [17], Arduino is combined with open source graphical programming tool to control a real robot. Williams [18] introduces a platform of LabVIEW and Arduino to teach PLC programming in a graduate level instrumentation and control course. Tremberger Jr. et al. [19] discuss Arduino's applications in community college student projects, in particular, a miniaturized satellite, where the teaching protocol is implemented using LabVIEW data acquisition. In [20], a self-controlled automatic system is designed and implemented using LabVIEW and Arduino.

The engine that we work with is the General Motors (GM) LS2, intended to be the V-8 engines used on GM line of rear wheel drive vehicles. Figure 2 and 3 show the sensor manipulation setup in the automotive lab at Indiana State University. The control room can be seen in Figure 2, where the high-end PC running LabVIEW is connected to Arduino board/shield. The Arduino is wired to the dynamometer host PC, which communicates with the engine and sensors.

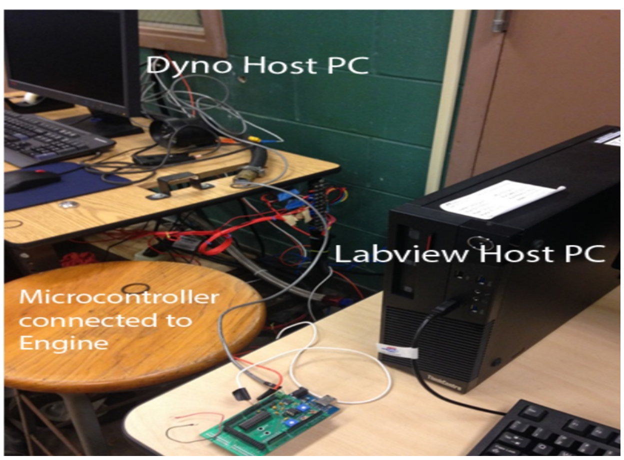

Fig. 2. Host PC and Arduino Boards

Figure 3 illustrates equipment in the engine room, which is adjacent to the control room. The cable from Arduino is wired with LS2 engine sensors.

We take a modular approach for the lab development. Individual modules are structured around one specific type of sensor, and progress from an introduction to hands-on experience and then move to problem solving. Such an approach has both field and pedagogical justifications:

- Engine sensors are highly integrated yet functionally independent. This feature provides the practical foundation for these units to be taught individually.
- Because of their diverse functions, some engine sensors may appear in other AET core courses. The lab modules can be flexibly integrated into these courses to serve the teaching needs.

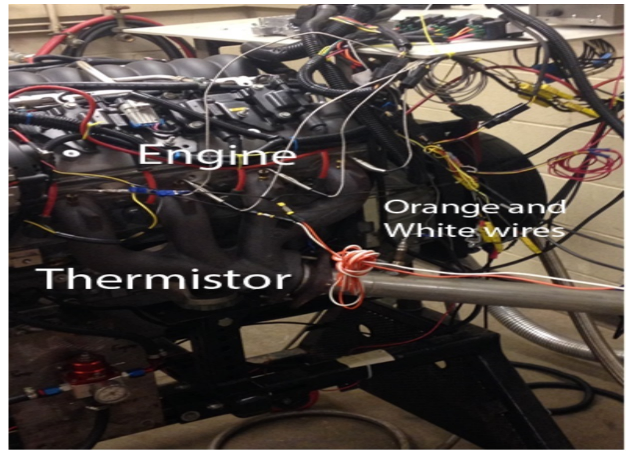

Fig. 3. Arduino Wiring to Engine Dynamometer

The engine sensors and their electrical characteristics can be found in [21]. For our project, engine coolant thermistor (ECT) sensor and crankshaft position sensor (CKP) are the focus of investigation in current stage.

ECT sensor is mainly used by the ECU to monitor the engine temperature and adjust ignition timing to avoid detonation. It is therefore a critical input to the computer that represents the engine running status. CKP measures crankshaft location and relays this information to the ECT. The ECU uses this crankshaft position information to time the spark properly, or on some systems for misfire detection.

We have completed the shields design and prototyping for ECT and CKP sensors. The PCB boards are shown in Figure 4 and 5 respectively. For board schematics and detail discussion on the board design, please refer to [22, 23]. In Figure 6, we show the front panel of the LabVIEW VI for displaying ECT sensor readings in real time.

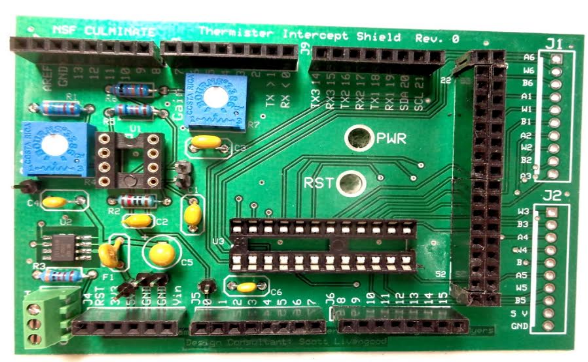

Fig. 4. Arduino Shield For LS2 ECT Conditioning

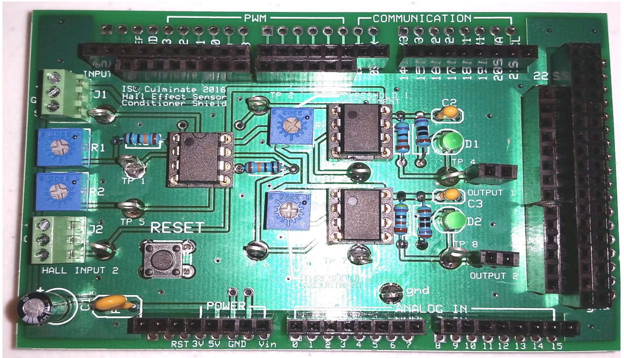

Fig. 5. Arduino Shield for LS2 CKP Sensor Conditioning

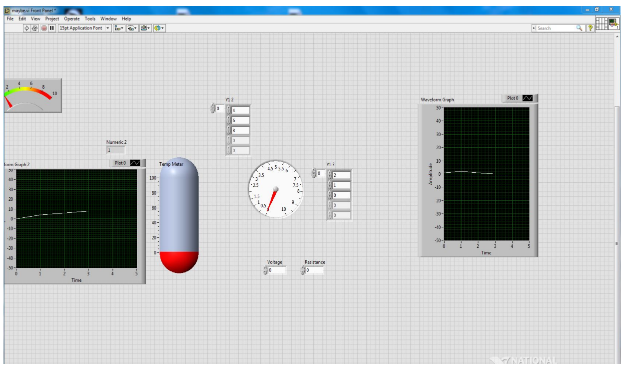

Fig. 6. LabVIEW Interface for Arduino Shield

III. Assessment Plan

We develop the assessment plan to evaluate student learning enhancement. The expected outcomes include increased student knowledge on MCU integration in automotive industry, and increased awareness of the interdisciplinary nature of technology fields.

The assessment will be carried in three core AET courses at Indiana State University: Engine Systems and Controls, Automotive Chassis, and Body Control System. These courses will integrate one or more microcontroller modules in their teaching materials. The students enrolled are the primary customers of the boards, and will participate in the assessment process either in the control group or training group. The control group will use the existing automotive lab kit, while the training group will operate the Arduino boards and LabVIEW.

There are two assessment tools in place for this study. The direct measure focuses on gauging students' mastering, quantitatively, of the engine sensor working mechanism. A pre-post design will be used to assess gains in student knowledge for each subject. The assessment will be based on standardized tests at the beginning and end of each course. The tests will be designed by AET faculty for subjects that are supposed to be impacted by the execution of project. Student individual skills will be assessed through the course via assignments and project reports. To assure the assessment results to be unbiased, we will make all groups as homogeneous as possible. Specific actions include: *a*) each group should be of roughly equal size; and *b*) the student background across the groups should be roughly identical, which means in each group student demographics and academic preparations should have similar distributions. The results from the pre-course standardized test will also be a key reference in dividing students into groups. We have learned from our past assessment experience using control and training groups that this is a very important step and is often overlooked in practice. If we simply set up groups randomly with no consideration of groups being "comparable" with each other, it will be difficult to distinguish the assessment data and draw a convincing and consistent conclusion on the approach's merits.

The indirect measure comes in the form of end-of-semester questionnaire, which aims at soliciting feedback regarding their experiences with the Arduino/LabVIEW suite. Questionnaire is commonly used for collecting cross-comparison data in various engineering curriculum assessment [24, 25], and some of the qualitative questions for our study are listed below:

- Q1 Impact of labs on understanding engine sensor?
- Q2 Connection between the lab and theory?
- Q3 Sufficient guidance on how to do labs?
- Q4 Understanding of learning objectives before lab?
- Q5 Understanding of learning objectives after lab?

Responses can be in the range of 1 to 4 for each questions. The data is analyzed using only descriptive statistics.

IV. Summary

In this work-in-progress paper, we introduce two Arduino shields developed collectively by computer and automotive engineering technology faculty as a fresh attempt to use open source microcontrollers to upgrade automotive laboratories, and help students better understand the collection, monitoring, and communication of engine sensor signals. The proposed assessment plan consists of both direct and indirect measures that when executed, will gather both quantitative and qualitative data to shed light on the effectiveness of boards in improving automotive students' literacy in microcontroller and its applications in the industry. We need to emphasize that due to the class size, the number of sessions per semester, and the frequency the classes are rolled out, it will take several data collection cycles before the sample size reaches a meaningful level. Therefore conclusive assessment results will not be available in the short run. However we do expect to use the responses from every cohort to guide new shields and lab teaching materials development. And we will look for collaborative teams in sister programs who are willing to pilot our Arduino boards in their courses and help us expedite data collection. The work is to be commenced on altering signals through the high-end user interface before they are passed on the real ECU to complete the closed-loop system.

Acknowledgment

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