AC 2008-2707: APPLIED ENGINEERING WITH LABVIEW: EXPERIENCES FROM A PLUG-IN HYBRID PROJECT

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Applied Engineering with LabVIEW: Experiences From A Plug-In Hybrid Project

Abstract

In this paper we discuss a primarily undergraduate project conducted during the 2006-2007 academic year with the goals of converting a stock Toyota Prius to a plug-in hybrid having enhanced electric only range capability. This project afforded the author with an opportunity to help with the utilization of National Instrument's Laboratory Virtual Instrument Engineering Workbench (LabVIEW) and a National Instruments compact RIO (Reconfigurable Input/Output) embedded controller in an applied engineering design project. This is a relatively new embedded system controller which, through the use of LabVIEW software applications, can be used as a stand alone real-time controller. This paper provides a background of the project and the role of LabVIEW and the compact RIO device. It also provides a description of some experiences related to introducing this system to undergraduate students, and later graduate students, having little background in rapid prototyping, real-time controllers, and the HS-CAN (High Speed Controller Area Network) communication protocol and standard. This type of automotive conversion project provided an excellent venue for introducing the students to a systems oriented approach to engineering design, from sensor measurement and vehicle interfacing to electrical energy consumption and strategy implementation on some of the most advanced vehicle technology available today.

Introduction and Background

A unique and successful degree program at Minnesota State University, Mankato is the Automotive Engineering Technology (AET) undergraduate program. Unique in that it is one of the only, if not the only, ABET accredited program of its type in the United States with numerous graduates each year pursuing primarily automotive technology and engineering test and development careers in industry. As part of the program, undergraduates complete a two semester (one year) senior design project related to an automotive system development, student competition or other automotive related research effort. During the 2006-2007 academic year, a group of students chose a project to modify and enhance the capability of the Toyota Prius Hybrid vehicle. Specifically, their goals included converting the vehicle fuel system to accept Ethanol blended fuels, enhancing the on-board battery capacity, modifying the vehicle for electric-only operation beyond launch and overall improvement of fuel economy with a target of around 100 mpg. With the use of a 2006 year Prius and a strong team effort, many of the project goals were accomplished. Modifying the on-board battery pack posed some challenges. Due to the lack of detailed knowledge of the operational characteristics of the Prius battery control unit (BCU), the students decided to interface the modified battery pack such that the Prius vehicle was not aware of the modification (i.e. masking the change to the BCU). There are numerous Prius conversion projects across the United States in various stages of development. A search through the internet yielded a similar endeavor: The CalCARS PriusPlus project [1]. In this conversion the stock Nickel Metal-Hydride (Ni-MH) battery pack was replaced with a Lead-Acid (Pb-Acid) chemistry pack with the same pack voltage as the stock battery pack. The BCU was sent similar fractional-pack voltage measurements from the new pack as provided by the stock pack in an effort to mask the battery pack change from the BCU. However since the charge and discharge curves for the two different battery chemistries are different, the voltage measurements provided to the BCU were supplemented with offsets to avoid alarm conditions in the Prius. The PriusPlus project integrated these voltage offsets via supplemental electronics and manually adjustable analog controls. A similar conversion methodology was attempted by the AET students. A Pb-Acid chemistry pack was developed with approximately six times the energy capacity as compared to the stock battery pack. Implementing a similar auxiliary controller interfaced to the BCU was considered excessively challenging given the limited student expertise gained in the AET degree program for developing integrated circuits and in working with electronic components. Therefore an alternative was considered which incorporated an embedded systems approach and provided an opportunity for the students to learn about applied high speed automotive communication and system control combined using the LabVIEW application. The National Instruments cRIO was chosen as the embedded system platform based on its low relative cost and the capability to interface the tool with LabVIEW. In this way an automated control strategy could be implemented removing the necessity for operator-based manual adjustments. All of the project objectives were not achieved at the completion of the senior design project period. Two graduate students from the Manufacturing Engineering Technology (MET) program, under the guidance of the project advisors, continued working on the remaining project objectives. Their experiences, to date, are also summarized in this paper. The paper is organized in multiple sections. Section 2 introduces LabVIEW and describes its use in the Prius conversion project. Section 3 introduces the cRIO hardware, describes its intended use on the project and discusses the outcomes of the student efforts put toward this system. Section 4 compares and contrasts the capability of the AET undergraduate students and the graduate Manufacturing Engineering Technology (MET) students (having an AET undergraduate degree) to incorporate the cRIO system into the conversion project. Section 5 provides some concluding remarks.

The entire scope of the conversion project will not be discussed in this paper, however aspects of the project related to the use of LabVIEW and the cRIO system will be discussed. Additional background on the entire project can be found in the project's final report [2]. Refer to figure 1 for an overview of the conversion project scope.

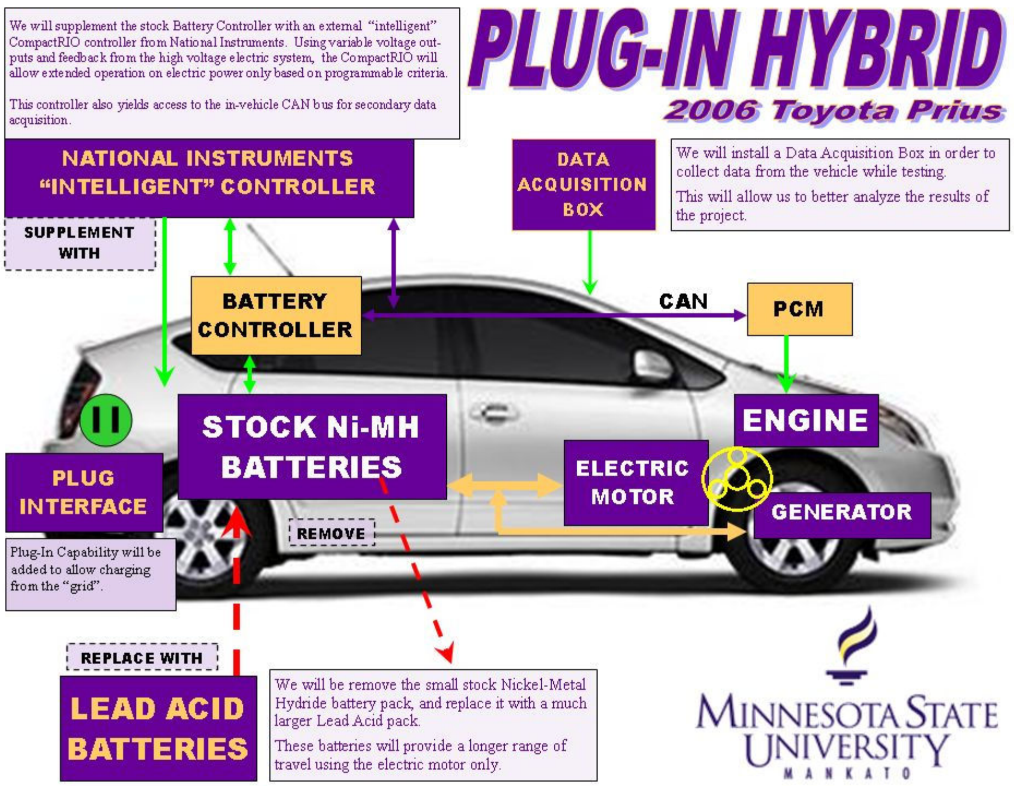

Figure 1: Diagram of the components of the conversion project.

LabVIEW and Real-Time I/O

The intent to incorporate LabVIEW into the AET curriculum has existed prior to the 2006-2007 academic year and this project provided an avenue to fulfill that intent. LabVIEW is a graphical development environment software package which runs on a personal computer and allows the user to interface with data acquisition and control systems hardware, external to the computer, using a block diagram interface and Virtual Instruments (or VIs). The software was originally intended to interface multiple instruments but has expanded to incorporate data acquisition, signal conditioning, real-time control and communication and simulation as well as providing an interface for embedding various types of programming language code. LabVIEW VIs have a front panel interface with virtual knobs, switches and data entry along with graphs and other data output constructs. The VIs also have a block diagram which details the interconnections between various blocks to execute some set of desired tasks. Some blocks also link the processing occurring in the block diagram to the I/O occurring in the front panel. To facilitate the processing or simple I/O of data to and from the VIs, hardware which digitizes the data external to the computer must be used in concert with LabVIEW. Various options are available, one of which is the cRIO and is available through National Instruments. The cRIO will be discussed in more detail in the next section.

A significant portion of the student project involved measurement of key vehicle data. This data included periodic high voltage battery pack voltage measurements, battery pack currents, battery pack temperature measurements from multiple surfaces of the battery pack and other vehicle operational data. In the case of the Toyota Prius vehicle, most of this information is internally measured by the vehicle and transferred between vehicle subsystems through the high speed controller area network (HS-CAN). This communication network is prevalent in many passenger vehicles built within the past ten years. The communication standard, originally designed by Bosch, has been around for a longer period but its widespread adoption did not occur immediately. The HS-CAN within the Prius vehicle provides a real-time representation of important vehicle measureables and status data. The student project team used a CANUSB^{TM} interface cable and hardware specific software drivers to process the serial data within LabVIEW. A screen shot of an earlier version of a VI used to read HS-CAN data is shown in Figure 2. CAN-related training in the AET curriculum prior to this project was limited only to the use of standard diagnostic tools. The training did not discuss the CAN protocols, message structure nor timing. In addition, topics related to microprocessors, microcontrollers or embedded systems are also not covered as part of the AET degree coursework. This project provided an opportunity to expose the students to these topics to gain some appreciation for what is happening behind the diagnostic tools and vehicle computers.

The undergraduate students were directed to complete tutorials on the LabVIEW software package and develop, starting with example VIs, usable VIs which measure and display vehicle parameters considered important and available on the CAN. Data specific to the operation and architecture of the Prius CAN is available from multiple public sources on the internet and these sources were leveraged to parse the particular messages containing desired vehicle data. For many of the students involved in the project, this was their first exposure to CAN communication. The author provided a short workshop (approximately 2 hours) for the group to review binary and hexadecimal number systems, introduce high speed communication and the CAN protocol and data frame structure, and to give them an opportunity to practice translating raw hexadecimal data frame information read from the Prius. This mini workshop provided an opportunity for the advisors to assess the level of student competency for working with CAN and also provided an opportunity to apply Directed Paraphrasing [5] to assess which students would be most capable to lead the effort for the data communication aspects of the project. Project area leaders are often tasked with generating presentation slides, providing explanations of project specifics during tours of the laboratories, etc. Given the student's limited experience in block simulation and in high speed communication, the author provided a portion of a VI which utilizes programming blocks to generate numerical transfer functions between the CAN message raw data and the desired measurement information (i.e. transfer functions for the CAN message information). This "template" was used as a building block. The students were able to modify it to read and parse additional CAN messages using similar block constructions. The learning experience was two-fold. Not only did the students gain an understanding of the CAN protocol message timing and field types, but also an understanding of integrating arithmetic operations in LabVIEW. In addition the students were able to build a usable front panel containing analog gages similar to what might be implemented in the dash of a test vehicle. Much of the real-time I/O interfacing for the high speed communication is provided as background processing within LabVIEW. The cRIO was chosen to provide feedback control capability to control the high voltage battery pack voltage offsets. Experience with the cRIO will be discussed in the next section. Due to time constraints and a longer than anticipated learning curve, the functionality of the cRIO was explored solely by graduate students participating in the project and by the author.

Incorporating the cRIO

The cRIO is an embedded controller designed to operate as a remote or stand alone processor capable of performing real-time control and data acquisition tasks. It contains a high speed processor and large Field Programmable Gate Array (FPGA) which can be configured for time critical processing tasks. The cRIO interfaces with LabVIEW and was intended to operate as a self contained system for CAN communication, data I/O and data processing for the conversion project. The configuration of the cRIO is shown in Table 1. Specifically, the cRIO was intended to replace the computer system running LabVIEW and the CANUSB^{TM} interface cable. In addition, the cRIO would provide control signals to regulate the application of offset voltage to the high voltage pack voltage measured by the BCU. In other words, if the high voltage battery pack voltage, V_P, was 200 V an offset of -10 V could be added yielding 190 V. In this way, the BCU would interpret the high voltage pack voltage as 190 V and control (limit) the current charge and discharge maximums according to the internal BCU strategy. The capability to offset the actual battery pack voltage is a very important control function when using a replacement battery pack having different battery chemistry. For example, if a replacement Pb-Acid battery pack is at a 50% charge level, the voltage at that charge level constitutes a lower expected charge level for a Ni-MH battery pack. More importantly, the BCU interprets the higher than expected slope of the battery pack discharge curve as an indication of pack degradation or failure prompting a degradation of available performance from the vehicle.

A sample project available as part of the LabVIEW software package installation provided the means to configure the cRIO for CAN communication however the usage of the cRIO was not extended beyond this point by the end of the project period. The primary reason for this stems from the lack of student team depth in electronics. The plug-in capability briefly mentioned in the Abstract required the development of a custom charging circuit design in order to reduce project costs. This custom design was developed by the author and constructing the charger proved to be a challenging task for the sub-team of students assigned to the task. Packaging of the charging electronics, the replacement battery pack, and the components required to incorporate Ethanol-blended fuels and the completion of other key design tasks and testing in addition to the electronics portion of the project overwhelmed the students. It is apparent that the investment of student time and resources necessary to integrate the cRIO for a project such as this was not adequately considered. However, the undergraduate students did experience an appreciation for the complexities involved in a hybrid vehicle modification project and were able to complete a majority of the project goals and tasks. At the completion of the project period, two graduate students were recruited to participate in completing the outstanding (uncompleted) goals of the senior design project. The advisors felt the level of depth required to complete the open tasks required a longer-term focus than could be expected from a single year undergraduate design course. The contrast in experiences with LabVIEW and the cRIO systems between the undergraduate senior design students and the graduate students is described in the next section.

Undergraduate vs. Graduate Experience

The undergraduate experience was broad and impactful. The starting point for the undergraduate students working on the Prius conversion project was limited to no exposure to LabVIEW, no exposure to the CAN protocol, and little to no exposure to

		cRIO-9004 Academic Bundle with 8-slots	
Slot	Card Type	Description	Intended Use
1	NI 9853	2-channel CAN communication module with serial interface	CAN node for CAN data input
2	NI 9263	4-channel 100 kS/s analog output module	voltage offset driver
3	NI 9401	8-channel 100 ns digital I/O module	digital sensor I/O
4	NI 9206	16 differential analog inputs	analog sensor inputs
5	None	None	Future Expansion
6	None	None	Future Expansion
7	None	None	Future Expansion
8	None	None	Future Expansion

Table 1: Hardware Configuration for cRIO

hybrid electric vehicle systems. The students were able to gain extensive experience in all of these areas including proper test protocols and procedures and safety procedures associated with high voltage battery packs. In addition, the students were able to integrate their programming background into the project to a limited extent. The undergraduate AET curriculum includes a programming course where a number of programming languages and software are covered in varying degrees of depth. The graduate students focused primarily on the software integration efforts and the cRIO. Two graduate students participated nonconcurrently with limited success although a larger proportion of their time was dedicated to the integration of the cRIO as compared to the undergraduate

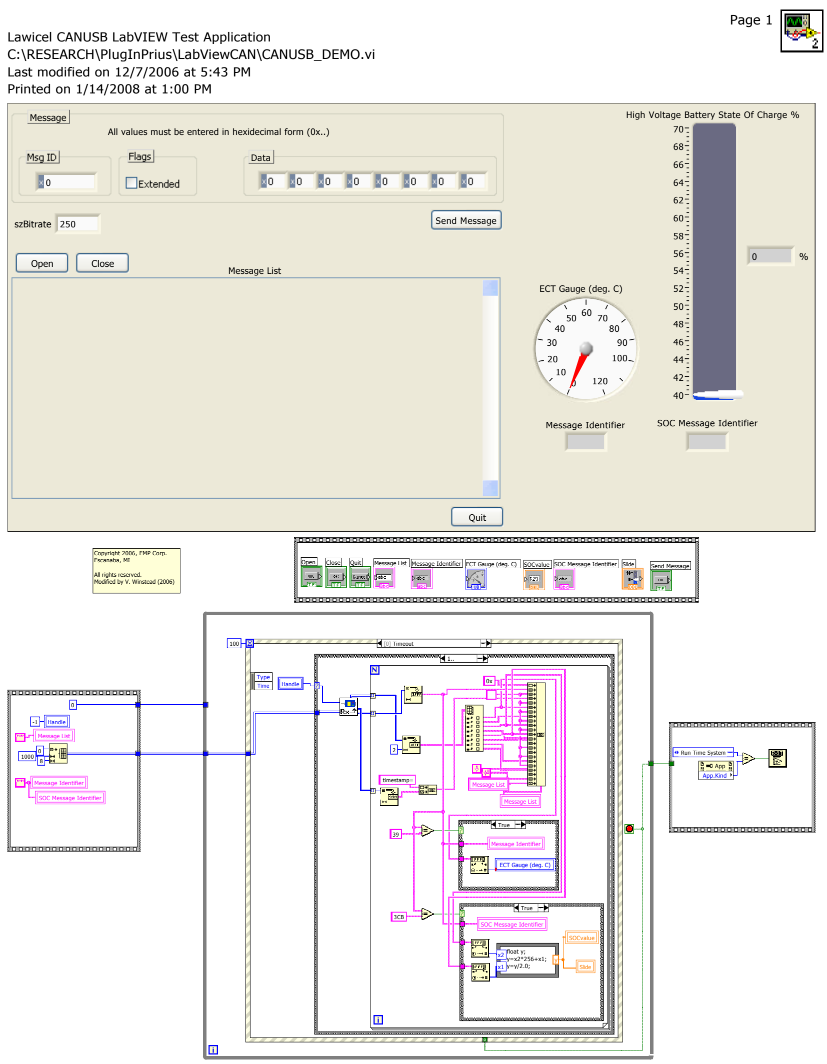

Figure 2: Block diagram and front panel for an early version of the CAN communication interface in LabVIEW. Reproduced with permission from EMP Corp.

students. The graduate students were able to use the cRIO for CAN communication and to record pertinent CAN message data. However, for similar reasons as compared to the undergraduate students, the graduate students were unable to design the interface circuitry required to generate the battery pack voltage offsets. The cRIO hardware was a new and challenging aspect of the project and represented the bulk of the uncompleted tasks for the project as a whole. Familiarization with LabVIEW required as much an effort from the graduate students as from the undergraduate students which was unexpected, however the exposure to LabVIEW and block diagram driven programming was nonetheless useful and enhanced their degree program.

Conclusions

The Prius hybrid plug-in conversion project was challenging due to the multitude of tasks, the variety of disciplines required and the imposed time constraints. Incorporation of LabVIEW and the cRIO (to some extent) did enhance the outcomes of the project and provided the students with additional tools which will be valuable to them in the future. The project would have benefited greatly from the involvement of electrical engineering or electronic engineering technology students from the university. This will be encouraged more strongly on future projects where interdisciplinary participation would enhance the outcomes.

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