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Implementing Embedded Control into Projects Designed by Students With Little or No Programming Experience

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I finished my Batchelor's in Electronics and Instrumentation Engineering. I also completed my MS in biomedical engineering. Currently, I am a 2nd year Ph.D. candidate in Biomedical Engineering, focussed in Biomedical Imaging. My thesis is using Ultrasound and Photoacoustic Imaging for designing and developing novel Image-guided procedures to treat diseases. I had 3 years of experience in designing Arduino based projects for Students. I was involved in the development of custom Arduino boards and add on Arduino modules for a company I worked during my undergraduate days. I have designed more than 30 Arduino based projects including EEG controlled robotic arm, Rehabilitation devices, ECG based pocket doctor, Alexa based speed monitoring device, Nursing Simulation Temperature Device, Smart Image-Guided Mapping Autonomous Robot for Teeth Numbing, deaf-mute interpreter and ultrasound elastography device. I have worked in Imaging projects involving MRI, ultrasound and Photoacoustic Imaging. I have won 2 hackathons, several Arduino competitions, and poster competitions. My aim in life is to combine my knowledge of robotics, electronics, and medical imaging for the development of Image-guided technologies for a better tomorrow.

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James Lenn has been at Wayne State University since 2013, first as part time faculty and more recently as a Lecturer. He teaches a freshman design course and several electrical engineering courses. Prior to taking a position at WSU, he had worked in industry as an engineer and engineering manager for roughly 30 years.

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Marcis Jansons, Ph.D., P.E. Marcis Jansons has been on the faculty of Wayne State University's College of Engineering since 2008, researching topics in advanced engine combustion and optical diagnostics at the University's Center for Automotive Research (CAR). As an Associate Professor of the Mechanical Engineering Department, he teaches undergraduate and graduate courses on combustion engines, fluid mechanics and emissions formation processes. Prior to joining Wayne State, he has worked for the energy industry as an environmental engineer addressing air, soil and groundwater contamination; and served as an instructor of Mechanical Engineering at the United States Coast Guard Academy. Jansons holds B.S. (1990), M.S. (1992) and Ph.D. (2005) degrees in Mechanical Engineering, earning his doctorate from Rutgers University for his work on combustion diagnostics and infrared imaging. He is a registered Professional Engineer (P.E.). Jansons has authored over forty peer-reviewed, engine-related publications, and is a member of the Society of Automotive Engineers (SAE) and on the Board of Associates of the American Society of Mechanical Engineers (ASME), Internal Combustion Engine Division (ICED). He is a 2012 recipient of SAE's Ralph R. Teetor Educational Award, conferred in recognition of significant contributions to teaching, research and student development and a 2015-16 Fulbright Scholar. Jansons has twenty years' experience working with optical engines, and leads a research group of qualified and experienced graduate students. Jansons serves as the Director of Early Engineering Programs, administering the core group of STEM courses common to the various engineering academic programs.

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Dr. Jeffrey Potoff is a Professor of Chemical Engineering and Materials Science, and the Associate Dean for Academic for the College of Engineering at Wayne State University. Potoff received his PhD in Chemical Engineering from Cornell University in 1999, and his BS in Chemical Engineering in 1994 from Michigan State University. Prof. Potoff is interested on improving the engagement of engineering students in their coursework through the implementation of evidenced-based teaching practices.

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Abstract

This paper describes an approach to providing students in a hands-on, first-year engineering design class, who have little or no computer programming experience, with the opportunity to include embedded computer control into their projects. The design class introduces students to Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), design for manufacturing, three-dimensional (3D) printing. At Wayne State University, we desire to provide students with a rudimentary understanding of embedded control as part of the first-year design experience. However, time constraints imposed by the length of a semester focuses instruction on CAD, 3D printing and the engineering design process. This leaves insufficient time for an in-depth discussion of computer programming and other matters pertinent to embedded control. As such, a new initiative began in the Fall 2019 semester where embedded control systems can be incorporated into projects by students with little or no programming experience. To bridge the gap between the desire for providing an understanding of embedded control and the lack of time for in-depth instruction of pertinent skills, a set of "Standard Embedded Control Modules" have been developed for student use. Each module consists of a common standard electrical/electronic hardware component along with relevant standard software modules, which provide the intelligence to exercise control of those hardware components. Undergraduate Teaching Assistants, along with the Instructor, help student teams in selecting the modules required for their selected project. It is then incumbent upon the student teams to design appropriate mechanical interfaces, follow electrical build instructions, and define required functionality for implementation into their projects. This initiative was introduced in a handful of projects during the Fall 2019 semester and boasts a positive impact on making projects more realistic, capturing student interest, and generating enthusiasm among students. This paper will provide an overview of our approach, lessons learned, and future endeavors.

Introduction

For several years at Wayne State University, engineering design principles were introduced to students through the LEGO® robotics kits. However, in the Fall 2019 semester, a transition was made to using Computer Aided Design (CAD) and three-dimensional printing (3D printing). This shift was made for several reasons. First, CAD [1, 2] is a more useful skill to have for the job market, since many companies now require it [3]. Second, it gives students first-hand experience with manufacturing techniques, with a focus on 3D printing. This gives students insight into the more nuanced parts of manufacturing such as clearances, and capability of manufacturing.

Most projects require a motor [4] or have the necessity of control. A great example of this is the paddle boat project. It requires the team to add two motors to control speed and direction of the boat. It also requires some way to get information about which direction the boat should be going. Currently in a semester, most of the focus is on the development of CAD knowledge for use with the final project. Combine that with many students not having much contact time with programming and/or electronics makes adding motors or controls to a project a difficult task. Since it is not feasible to reduce the amount of time used for CAD instruction, it was decided to design “Standard Control Modules (SCM’s)” which allow students to use embedded control, while abstracting away most of the need for instruction on the details of how the modules work. In this paper, an overview of the approach taken to create these SCM’s is presented along with planned future developments.

Background

Near the beginning of each semester student teams are formed and final project selection is made by each team for development by semester’s end. Table 1 contains a subset of recent projects and a small description of what each project contained.

Table 1. Projects that have been completed

Project Name	Description
Bench Vise	Rotating base, jaws open to approximately 8 inches
Drawbridge (Mechanical)	Manually operated with handle using worm gear mechanism
Drawbridge (Electrical)	Implemented with Standard BE 1200 Embedded Control Module (switches and servo motor, controlled by software running on a micro-controller)
Electric Clock	Motor driven gearing/Geneva mechanism operating minute and hour hands
Elevator	Manually operated with handle, gears, pulley, and cable
Ferris Wheel	Implemented with Standard BE 1200 Embedded Control Module (switches and servo motor, controlled by software running on a micro-controller)
Mechanical Hand (Student Initiated)	Fingers with individual joints, palm, and wrist. Fingers opened and close under the control of a microcontroller programmed by students
Platform Jack	Scissor mechanism activated by handle driving rack and pinion gear assembly
Ratcheting Screwdriver	Student designed ratchet mechanism
Remote Controlled Car (Student Initiated)	Body, chassis, and wheels. Microcontroller programmed by students, utilizes Bluetooth module interface to smart phone for operator control
Remote Controlled Paddle Boat (Student Initiated)	One paddle on each side of boat, electronic control Implemented with Standard BE 1200 Embedded Control Module (Bluetooth interface and 2 continuous rotation servo motor, controlled by software running on a micro-controller). Bluetooth interface to smart phone for operator control
Self-Watering Planter	Ferris-wheel-like, controlled by Standard BE 1200 Embedded Control Module (microcontroller and motor)

Many of the projects, such as the Bench Vise or Ratcheting Screwdriver are well suited for purely mechanical operation. Others however, including the Elevator, Drawbridge, and Ferris Wheel can be enhanced using embedded control for autonomous action. Additionally, using embedded control opens a new range of projects such as remote-controlled (RC) cars and boats.

Approach

To provide students with embedded control without the need for in depth instruction, several modules have been developed including an Arduino microcontroller with which students can interface. Due to the availability of ports for sensor interfacing, low cost and easy to learn coding language, Arduino was chosen as the microcontroller for projects. Arduino has been used in various projects including Remote-controlled (RC) cars [5] and home automation [6]. These modules consist of the hardware and software to perform basic operations and generally need to be fine-tuned by either an ambitious student or a member of the instructional staff (Instructor or Undergraduate Teaching Assistants). The SCMs enhance the projects by adding functionality and they consist of input modules, control modules and output modules which allow control of standard hardware sensors and actuators.

USER INPUT MODULES

User Input modules provide the bridge between the user and the controlling software using either hard-wired or wireless communication. In some cases, input modules act as a failsafe for projects driven entirely on sensor data. Joysticks and push button switches are examples of devices typically used in wired communication. Hard-wired inputs are further divided into analog and digital. In each case a voltage level is provided corresponding to the activation position of the device. A joystick is an example of an analog input which provides a continuous range of values between 0 and 5 volts corresponding to the physical position of the stick in each of two axes. On the other hand, digital inputs provide a value of on (5 volts) or off (0 volts). Analog inputs are used in projects which require motion or other outputs to be controlled over a continuum of values, rather than just on or off. An example of using an analog input is in controlling the motion of a robotic arm in 2 axes where velocity of motion in each axis is controlled by the position of a joystick. Digital inputs include push button switches, toggle switches, and D-pads to provide user control of projects. Digital inputs provide a value of “1” (5 volts) when activated and “0” (0 volts) when released. Examples of projects using digital inputs include the control of a drawbridge, Ferris wheel, and elevator.

Where wired communication is not feasible, modules based on wireless communication can be implemented. They offer flexible control to students who are building RC cars, boats etc. In addition, these modules offer a more convenient approach as students can control their projects with smartphones or laptops using a Bluetooth interface. Bluetooth user input modules were built to be compatible with two major operating systems (OS): android and IOS, since most smartphones used by students were based on those platforms. These modules use universal asynchronous receiver/transmitter (UART) communication and can interface with a wide range of microcontrollers and microprocessors. The modules for android devices and windows OS-based laptops were built using the HC-05, which follows the IEEE 802.15.1 standardized protocol, and for IOS devices, the HM-10 is used. For project purposes, both modules are programmed in the slave mode and are connected to the Arduino boards. Control signals to these modules are received from existing smartphone-based applications in the form of character data.

User input devices are either (A) hardware-based inputs or (B) software-based inputs. Joysticks and push button switches are examples of hardware-based inputs, while smartphones are examples of software-based inputs. Software-based inputs are divided into graphical and textual user interfaces. Graphical interfaces use virtual buttons displayed on a touch screen and are available as smartphone applications. In this case, specific character data is encoded into each of the controls displayed on the user interface. Textual user interfaces are also available as smartphone applications. Like graphical interfaces, they transmit character data, however, these values are manually keyed into the device (smartphone) by the operator. Examples of projects where graphical controllers fit include RC cars and paddle boats. Application examples of textual interfaces could include the draw bridge, Ferris wheel and self-watering planter. Through data processing and manipulation, microcontrollers can convert the responses into specific actions. Assignment of specific actions can be matched with the responses through minimal programming by the students. In addition, analog and digital joystick controllers can be combined to provide a more customized option for student projects.

OUTPUT MODULES

Output modules act as the indicators, legs and hands of the project. Based on inputs from sensors and the user, the microcontroller provides control signals to the indicators and actuators, which in turn add motion to and provide status of the project. The types of actuators used include servo motors and direct current (dc) motors, while indicators include light emitting diodes, Liquid Crystal Displays and piezo-electric buzzers. Servo motors are further classified into positional rotation (SG90) (180^0) and continuous rotation (FS5103R) (360^0) servo motors. The versatility and easy programming make servo motors a good fit for most projects. Positional rotation servos have been used in the steering mechanism of RC cars, continuous rotation servo motors in the paddle boat and dc motors for the drive mechanism of RC cars.

SENSING MODULES

Sensing modules provide the interface between the actual sensor hardware and the control module. One type of sensor being used is the ultrasonic sensor which works based on the principle of transmission and echo of sound waves. Ultrasonic sensors can be used in self-parking RC cars, obstacle avoiding RC cars, and autonomous draw bridges. The addition of autonomous features to devices and vehicles (Tesla etc.) is becoming more prevalent as sensor technology improves. Providing students with exposure to designs that take advantage of the capabilities provided by the newer sensors allows students to gain a plethora of relevant knowledge and develop more enhanced and innovative projects.

CONTROL MODULES

These modules implement algorithms which control actuators and indicators based on user and sensor inputs. An example is the algorithm which monitors inputs from an ultrasonic sensor and raises a drawbridge when a vessel is detected at a predetermined distance from the bridge. The distance measuring capability is based on the reflection of sound waves. The time interval between transmission of a pulse and the reception of its echo determines the distance which is calculated as:

$$\text{Distance} = \frac{\text{Speed of sound} * \text{time}}{2} \quad (1)$$

Based on calculated distance, the control module signals the appropriate output module to raise the bridge. Feedback from the drawbridge in the form of a limit switch informs the control module to cease the operation of raising the bridge.

Future Endeavors

Going forward, we will be compacting the modules into code libraries that students can use directly. The libraries will be abstracted in such a way that students are able to configure their desired system by following a simple set of instructions. First, one of four types of input module will be chosen: Joystick, Bluetooth, Computer-Serial, or sensor based. Then, the appropriate control module will be selected. Finally, the selection of an actuator module will be made. Currently actuator modules consist of interfaces to servo motors, of which there are two types, continuous and limited range, and dc motors. Consideration is also being given to creation of a module for stepper motors but at this point, no classroom application has been identified. Figure 1 shows the layout of data flow for the modules.

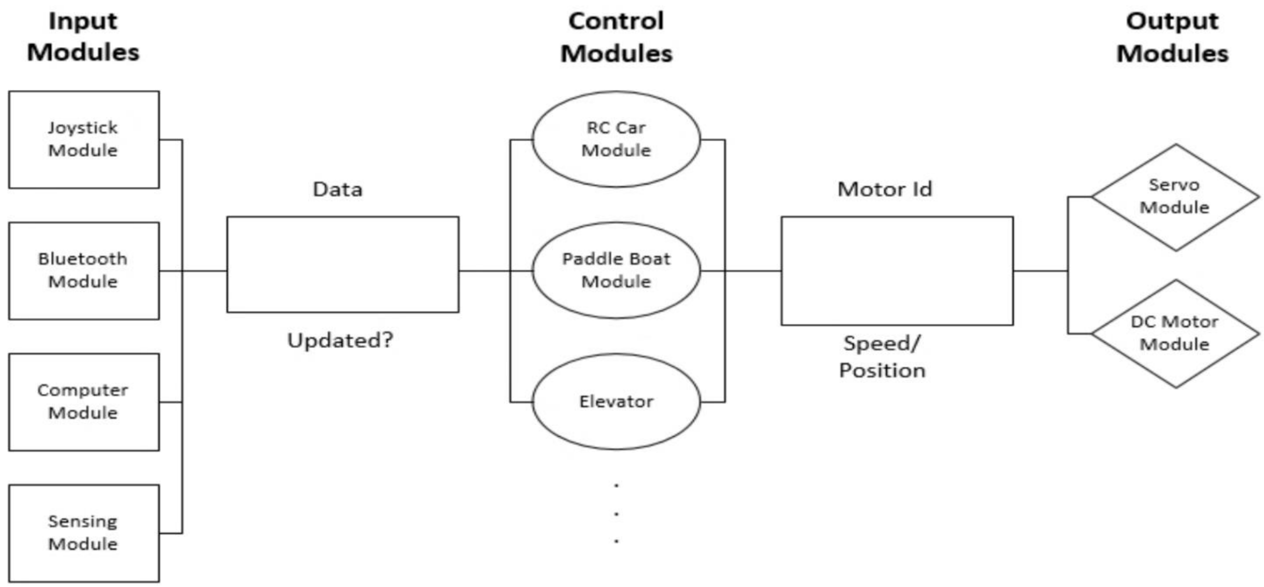

Figure 1: Schematic representation of the modules and the flow of data.

These modules will be implemented as a software architecture within the microcontroller which will control the data corresponding to each of the modules. Each input module will service new data from its respective input device and provide them to the control module. For example, an RC car driven through a Bluetooth module will require the input software module to poll the Bluetooth device and output a single character such as “W” for forward, “S” for reverse, “A” and “D” for left and right to the control module

The control modules will incorporate a state machine which updates its future state based on inputs received and its current state. For example, if the new data is “W” and the machine is in the “W” state. Nothing will happen and it will wait until a new character is available to read. If, while in the “W” state the new character “S” is provided, the control module will command the output module to change the state of the output software to match. The output module will then stop the car by writing the appropriate values to the motors. In general, the controller module will receive data from the input module. Based on that data and the current state of the machine, the control module will update the output module which will set the state of the appropriate hardware.

With regard to hardware modules, future plans include the development of a tailored actuator board that can control up to six servo motors and up to two dc motors with an H-Bridge which provides a means for controlling direction and speed for each dc motor.

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