2023 ASEE Workshop Combining Arduino and MATLAB for Controls Experiments

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At the ASEE 2023 conference, a workshop was delivered showcasing the integration of advanced features in MATLAB® and Simulink® software with Arduino® microprocessor boards for conducting control experiments. This document illuminates the successful strategies and pinpoints areas necessitating enhancements, discerned through participant feedback and empirical observations. It comprehensively articulates the required experiments and materials, emphasizing a practical, hands-on methodology. The workshop extensively utilized project-based learning (PBL) methodologies, harnessing a spectrum of economical hardware solutions. Moreover, it introduced alternative methodologies utilizing robust MATLAB simulation functions. The combination of student feedback and instructor insights is presented, offering valuable benchmarks for the workshop's efficacy. This workshop was developed as a joint effort between York College of Pennsylvania, McMaster University, and MathWorks®. This document is intended to function as a resourceful blueprint for future renditions of this workshop, whether facilitated by MathWorks or others, ensuring continuous improvement and knowledge dissemination.

Introduction

In the changing landscape of multidisciplinary engineering education, the integration of software and hardware has become indispensable for mechanical engineers and in other curricula. Contemporary engineering challenges demand proficiency not only in theoretical knowledge but also in practical, hands-on experience. The ability to interlace software control with physical hardware systems is crucial in cultivating versatile engineers equipped for the multidimensional problems of the modern world. This fusion not only deepens understanding but also enhances innovation as students learn to navigate and manipulate the interface between digital and tangible realms.

The workshop at ASEE 2023 [1] was crafted with these imperatives in mind, aiming to bridge the gap between theoretical constructs and their real-world applications. It focused on PBL, an educational approach that fosters critical thinking, problem-solving, and collaboration through complex and challenging projects that reflect the ambiguity of real-life scenarios. Hands-on activities were not merely ancillary; they were central to the learning process, ensuring that participants could apply theoretical principles in a tangible setting, reinforcing their learning through direct experience.

The cornerstone of this educational venture was the utilization of MATLAB [2], and Simulink and Arduino [3] as educational tools. MATLAB, with its high-level language and interactive environment, enables students to explore algorithms and create models easily. Simulink is a graphical modeling tool used to design algorithms and simulate physical systems. It enables students to learn about Model-Based Design, a development methodology commonly used in industry. Arduino, on the other hand, brings the power of microcontrollers to the students' fingertips, allowing them to interact with hardware directly and see the immediate impact of their algorithms. Getting started with these tools is facilitated by a wealth of community resources, tutorials, and user-generated content, making the initial steps into the world of software-hardware integration accessible even to novices. This workshop was designed not just to introduce these tools but to demonstrate their synergy and capacity to bring ideas to life and ignite the spark of engineering innovation in every participant.

Collaboration between MathWorks and Academic Institutions

The partnership between academia and MathWorks for conducting workshops represents a synergistic collaboration that benefits academics. We organized this workshop to show the value of MATLAB and Simulink (referred to collectively as MATLAB in the rest of this document) as learning tools for control theory activities and a conduit to programming with Arduino. It was hoped that this workshop would provide a good tutorial for our fellow educators of how the MathWorks toolchain could be leveraged for meaningful hands-on control and other PBL engineering problems.

3. Workshop Activities and Execution

The workshop centered on utilizing the MATLAB toolchain for controls education. Participants were introduced to the essential tools available in MATLAB and Simulink through two sessions, each lasting 1 hour and 10 minutes, with a 10-minute intermission.

In the first session, led by MathWorks engineers, attendees learned the fundamentals of leveraging diverse MATLAB functions to teach control theory and similar subjects. The participants gained practical experience by constructing and executing simulations on their workshop laptops. All necessary code samples and additional resources were provided. Participants explored a selection of the extensive controls-related content available in MATLAB. The session concluded with introducing the concept of Model-Based Design using a full-system simulation. This simulation included the controller and physical plant of the hardware setup to be used in the next session.

The second session delved into integrating MATLAB with physical hardware, specifically using the Arduino interface to sense and manipulate various devices. Participants received a standard Arduino kit, similar to the ELEGOO UNO Project Super Starter Kit[1], which they were allowed to keep after the workshop. This session aimed to provide experience using Arduino for sensing and control tasks, culminating in an actual control experiment. It involved basic experiments with specific input or output devices, a self-directed discovery challenge, and introducing a simple control device. Attendees were tasked with using their newly acquired knowledge to operate this device. Additionally, this session featured hands-on simulations of typical control systems.

The topics presented in each session were as follows:

MATLAB control functions seminar (Session 1)

- MATLAB Basics
- Dynamics Systems
- State Space
- Laplace Transfer Function
- Building simulations

MATLAB Arduino sensing and control seminar (Session 2 work in pairs or triplets)

- Sensing devices
- Controlling devices
- Controlling a system through Arduino with MATLAB
- How to complete these steps with Simulink, time permitting

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[1] Elegoo kits can be found on line: https://www.amazon.com/ELEGOO-Project-Tutorial-Controller-Projects/dp/B01D8KOZF4/ref=asc_df_B01D8KOZF4&mcid=80a5b47d61dc377992c3c25d65d73272?tag=bngsmtphsnus-20&linkCode=df0&hvadid=80882941400123&hvnetw=s&hvqmt=e&hvbmt=be&hvdev=c&hvlocint=&hvlocphy=&hvtargid=pla-4584482468293071&psc=1

The workshop did not require prior knowledge of MATLAB or Arduino programming, but some knowledge of these two technologies benefited the participants.

The following MATLAB toolboxes (version R2023a) were used in the workshop:

- MATLAB®
- Simulink®
- Stateflow®
- Simscape™
- Simscape™ Electrical™
- Simscape™ Fluids™
- Simscape™ Multibody™

4. Project-Based Learning (PBL) Approach

PBL has been shown to be beneficial for classroom motivation and learning. Blumenfeld et al. [4] argue for PBL's effectiveness in helping students learn. Additionally, their study examines the sustainability of motivation in PBL. Wilkerson et al. [5-6] have demonstrated strong student motivation to learn new topics using PBL within a capstone design program. These efforts have shown that students are likely to self-motivate, thus gaining more in-depth knowledge than typically found in classroom environments that cover only specific areas. Strobel et al. [7] have found that PBL is superior for long-term retention. However, their research also suggests that traditional approaches may be more effective in the short term. Control theory, a topic where examples are crucial to students' understanding, relies on mathematically intensive techniques, making learning through visualization a likely key factor. Therefore, it can be argued that hands-on experimentation is essential to grasping the outcomes of control methods.

It is unsurprising that most control books include numerous examples and project suggestions. The texts by Norman Nise [8] and Richard Dorf [9] contain extensive mathematical representations of physical systems. Furthermore, both texts heavily utilize MATLAB for plotting and displaying results. Nonetheless, the importance of hands-on projects is clear and often incorporated into control programs. Quanser is one company producing advanced control experiments for classroom use. These experiments frequently employ LabVIEW and require a significant financial investment by institutions to include them in the curriculum. Another consideration is the time invested in learning to use another software or hardware platform. Ultimately, students may be able to operate an apparatus. Still, they may not master the methods, focusing instead on the ability to use the software and hardware provided by the vendor.

Hardware Utilization and Cost-Effectiveness

One of our goals was to provide a low-cost alternative to expensive control experiments that are often unaffordable for smaller teaching colleges and. While MATLAB is widely used in academic institutions, control experiments often are not due to their high cost, which can amount to thousands of dollars, and the need for specialized software and hardware [10]. The value of third-party control experiments is significant, but they may not fit within every school's budget. Arduino hardware and software offer an open-source, non-proprietary, cost-effective, and flexible option for a wide variety of experiments and programming assignments.

During the workshop, we introduced an Arduino Uno interface equipped with a range of input and output sensors, including LEDs, motors, motor controllers, servos, and potentiometers for outputs, and potentiometers and ultrasonic sensors for inputs. We provided clear wiring instructions and easy-to-understand circuit diagrams for each assignment in self-paced handouts. Additionally, a final control project[2], which students could construct for less than one hundred US dollars, was presented and is depicted in Figure 1. MATLAB engineers also showcased software solutions for building a visual simulation of the project, which could be achieved independently of the hardware. In the final project, a ping-pong ball is blown up in a transparent tube by a fan driven by a DC motor. The objective of the control system is to hold the ball at a specific point in the tube by adjusting the fan speed. Due to the problem's nonlinearities, this proves difficult. However, using a robust PID, a solution can be found where the ball will oscillate around the target position.

Figure 1. Ping Pong Ball Experiment

Simulation Alternatives with MATLAB

We provided a simulation using MATLAB and Simulink as an alternative to hands-on experience. This may be useful in situations where hardware is not available. This simulation utilized a CAD model depicted in Figure 1 (the right half) and included physical approximations for the control system's motors, sensors, noise, and other. Tt also enabled students to delve into

[2] All the files used in the final project with details can be downloaded at: https://www.thingiverse.com/thing:6096270

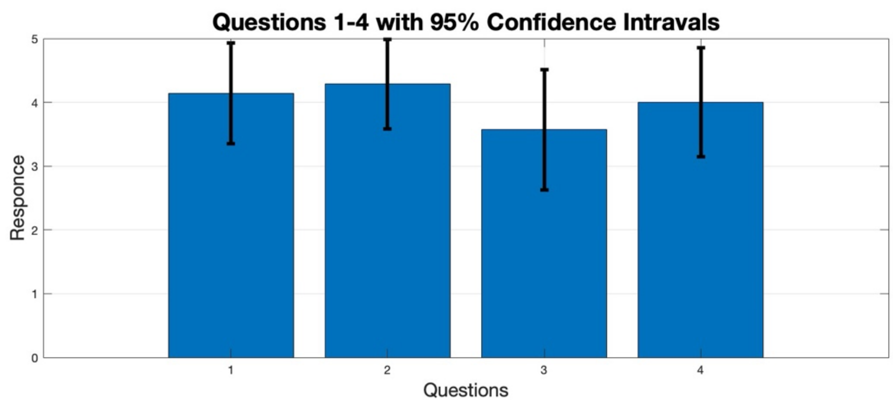
the problem's nuances and develop solutions for controlling the ball's position. Providing this simulated option allowed workshop participants to explore alternative PBL experiments that could be undertaken instead of the actual experiment. In addition, this process of using an entirely virtual setup is now commonplace in developing systems such as automobiles and aircraft.

Feedback and Observations

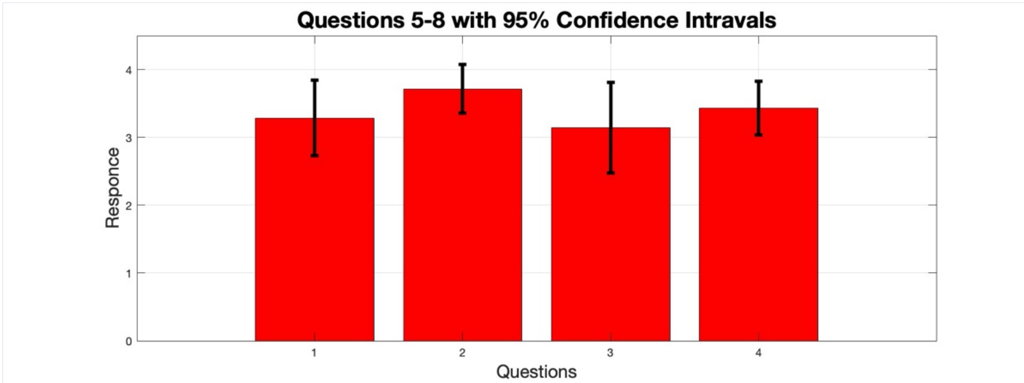
At the end of the workshop, participants were invited to rate their experience and what they learned from the sessions, with a five being very familiar and a one being unfamiliar.

Questions 1-4 are:
1. How would you describe your familiarity with MATLAB BEFORE the seminar?
2. How would you describe your familiarity with MATLAB AFTER the seminar?
3. How would you describe your familiarity with Arduino BEFORE the seminar?
4. How would you describe your familiarity with Arduino AFTER the seminar?

Most of the participants had relatively good knowledge of MATLAB and the Arduino prior to the workshop.

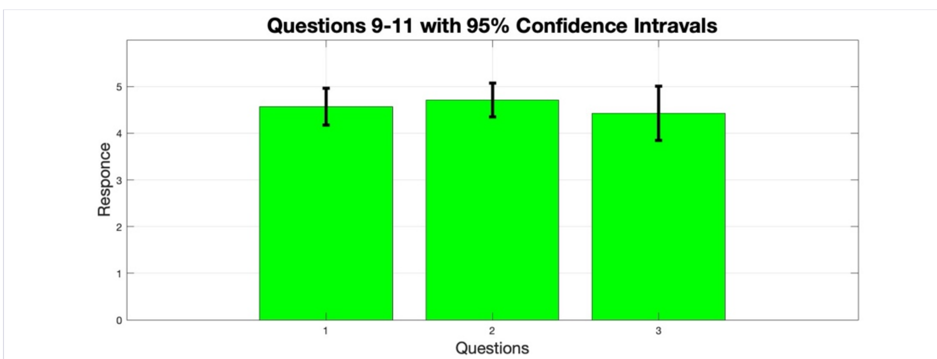


Question 5-8 were:
6. How often did you use MATLAB in your classes BEFORE the seminar?
7. How often do you think you will use MATLAB in your classes AFTER the seminar?
8. How often did you use Arduino in your classes BEFORE the seminar?
9. How often do you think you will use Arduino in your classes AFTER the seminar?



In these questions, a four meant very valuable, and a one not valuable. MATLAB and the Arduino microprocessor were considered as being valuable in the classroom prior to the workshop activities.

Questions 9-11 were:
9. How valuable did you find this seminar?
10. How would you rate the importance of including MATLAB in your engineering curriculum?
11. How would you rate the importance of including Arduino in your engineering curriculum?



In this set of questions, a five meant very valuable or important, and a one meant it was of no value or importance. The workshop was viewed as being valuable to the educational process.

Evaluation of Workshop Success and Areas for Improvement

The survey revealed that most attendees were already very familiar with MATLAB and its capabilities, and were incorporating the program into their curricula. However, they had not utilized the functionalities we introduced, which they found valuable. The verbal feedback received after the workshop was very positive, and we were encouraged to repeat the workshop the following year. During the debriefing, we discussed the observation that we attempted to cover too many topics in the allotted time, but the participants highly valued the hands-on portions.

Recommendations for Future Workshops

We plan to follow up on the initial workshop with a second. Our aim is to narrow our focus in the upcoming year and design the presentation to include more hands-on activities. As the participants observed, another beneficial aspect of the presentation was allowing everyone to work at their own pace with the provided worksheets. Additionally, the presenters circulated among the class, offering help where needed.

Conclusion

The ASEE 2023 conference showcased a fruitful collaboration between academic institutions and MathWorks. This partnership led to a successful workshop execution highlighting the integration of advanced MATLAB features with the Arduino microprocessor to conduct control experiments. The workshop not only shed light on effective strategies but also pinpointed areas needing improvement, guided by participant feedback and empirical evidence. The required experiments and materials were presented clearly, emphasizing a hands-on, cost-effective educational approach. PBL methodologies took center stage and were augmented by simulated MATLAB functions as a novel instructional method. The collective feedback from students and instructors provided essential benchmarks for evaluating the workshop's effectiveness. This document is designed to act as a detailed blueprint for subsequent versions of the workshop, maintaining its status as a vibrant, adaptive resource for knowledge exchange, whether facilitated by MathWorks or other entities.

12. References

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