Reinventing Control Education for the Modern ECE Curriculum

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"Reinvention" seems to be a topic of lively discussion in many circles these days and ECE is no exception. For the past several years, the reinvention of the ECE image or brand has been a significant topic as we reconcile our academic traditions with emerging societal and technological realities.

My company, Quanser, has a long history and pedigree in inventing and reinventing efficient lab test beds for validating formal control systems concepts as studied in teaching and academic research. Twenty years ago, commercialized control test plants for academia was, without argument, an innovation and their adoptions had a definite impact on quality of teaching and proficiency of research.

Today, in the shadow of modern mechatronics, robotics, and the Internet of Things, control can often seem somewhat parochial if not antiquated. We live in exciting times and there is no reason why a foundational concept like control cannot and should not be exciting. If you substitute the word 'control' with 'ECE', this statement still holds true. So perhaps a closer look at the challenges and opportunities in control can offer some insight into the larger question.

Which should come first … the physical system or the embedded controller?

Mechatronics is the amalgamation of a physical system and a computer to enhance its function. In an ideal world, our students should build proficiency and insight into both. In some sense, this philosophy is actually the foundation of most mechatronics programs throughout the world. A large proportion of traditional engineering science and mathematics courses are preserved and "pure" mechatronics courses are introduced. Mix gently and voilà, a capable mechatronics engineer emerges after four years.

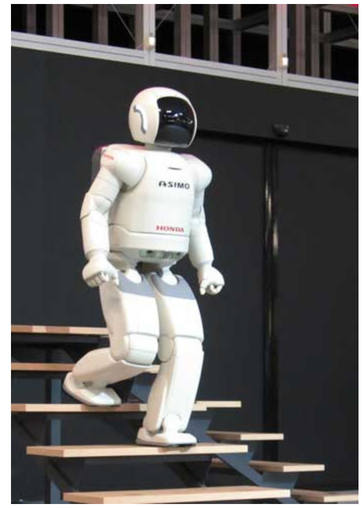
Anecdotally, most institutions seem to struggle to make such tidy outcomes happen due to essential challenges on both the physical systems and computing aspects. In the math and science courses, the problems are well known. They are often theory-heavy with insufficient integration of accessible, intuitive application contexts, and the concepts from other courses that undoubtedly are relevant to the topic in the real world.

On the computing side, the prevailing methodologies focus on the programming and integration challenges. The tools of computing typically are commoditized microprocessor boards in combination with common sensors and simple actuation such as hobby motors and lights. Largely, I have found that students enjoy these courses. They are hands-on and they are rewarded with a small invention that does 'something.'

The challenge, in my mind, is the reconciliation of the above. Putting it bluntly, can abstract theory ever be fun? In the case of control, the original Quanser answer has been, yes, it can be fun if you can see and feel physical systems balance or settle under the governance of a controller derived from mathematics. But in a world of computer-controlled everything, one can argue that simply physically replicating control theory is insufficient to appropriately capture the complexity of modern challenges and to offer insight into solutions. A modern evolution of the conventional controls lab, as good as it is, should encompass a strong dimension of the techniques of implementation and end-application.

High fidelity mechatronics

This is fundamentally a harmonization of complex physical dynamics of systems (conventional control) with mechatronic control. Control, as it is typically taught in the undergraduate sequence, is an essential part of mechatronics if and only if the dynamics of the physical system is important or of interest. Therefore a mechatronic implementation with sophisticated algorithm controlling finite sets of states, though important, is not consistent with the traditional control course.



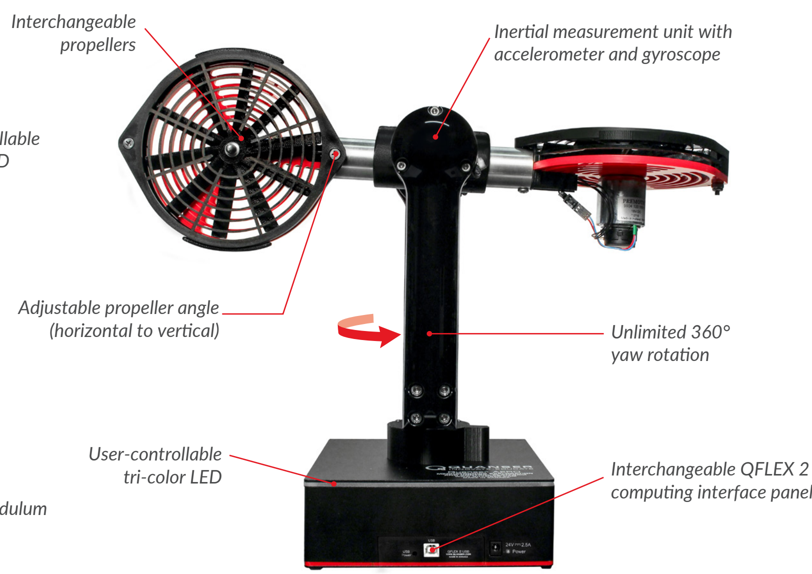
Conversely if the variables to control are physical and (mathematically) continuous in nature, in whatever physical domain, we have potential harmonization of control and mechatronics. Furthermore, once harmonized, the resulting concepts and methodologies may potentially be more relevant and motivating to students as mechatronics service as a tangible, technological bridge between the scientific concepts and the real world.

The argument for this approach is that some of the most important, motivating, "jaw-dropping" applications we see today fall into this category. The return flight and safe landing of the SpaceX rocket; autonomous aerial and ground vehicles; humanoid robots; so called bionics are examples of such applications. All of these exhibit complex continuous dynamics and more importantly it is applications like these (or their historical equivalents) that defined the techniques of control.

Mechatronic variations of control plants

One obvious step is to adapt existing control lab platforms to embedded device control. For example, Quanser's new QUBE-Servo 2 and Quanser Aero provide full support for conventional control but are also equipped with connectivity to microprocessors including common processor boards like Arduino® or Raspberry Pi®, or more refined devices such as NI myRIO designed for academic applications.

Additionally, these systems allow user to modify physical system configurations to increase dynamic complexity. The QUBE Servo 2 has a magnetic coupling interface that lets you add custom components. The Aero's rotors and links can be readily repositioned to support a broad range of flight-oriented experiments including helicopter flight or even quadcopter flight. In both cases the expectation is that these add-on pieces are designed and fabricated using the 3D design and printing tools. So from this approach, there is a technological bridge between conventional dynamical approach to control to several of the most important ideas in modern mechatronics including embedded programming and maker movements.



Quanser's QUBE-Servo 2 and AERO provide full support for conventional control and can connect to microprocessors via QFLEX™ 2 I/O framework.

Practical challenges

Even with such an “obvious” evolutionary step for control labs, we are still faced with that all too familiar issue at universities: time constraints. How do we add new concepts to an already stuffed course or program? Professors may also question the role of manual analysis techniques that permeate the traditional control course. Though an optimistic view, an increased focus on the physical dynamics on the platform of mechatronics actually increases attention on the essential dynamics and models now in a more relevant, intuitive and possibly, more complete way.

Additionally there is the issue of class vs. lab vs. homework (or flipped class). If a course has not historically had a lab component, it may not be easy to physically add a lab component due to either facility mismatch or possibly institutional regulations.

One interesting direction that Quanser is pursuing is the notion of significantly increasing the efficiency of the lab set-up and procedure – i.e. eliminate as much of the effort normally dedicated to students hooking up, calibrating, and coming to grips with the lab set up and isolate the lab time exclusively to concepts. The goal is to facilitate a lab model where a scheduled tutorial time is used and a single hour is sufficient to get the key hands-on experiences introduced. In a recent collaboration with the Lassonde School of Engineering at York University in Canada, Professor Nima Tabatabaei chose to do a significant portion of his lectures within the lab environment itself thereby introducing the theory in the presence of the equipment. This is only feasible within a high-efficiency lab framework.

A complete view of control and mechatronics

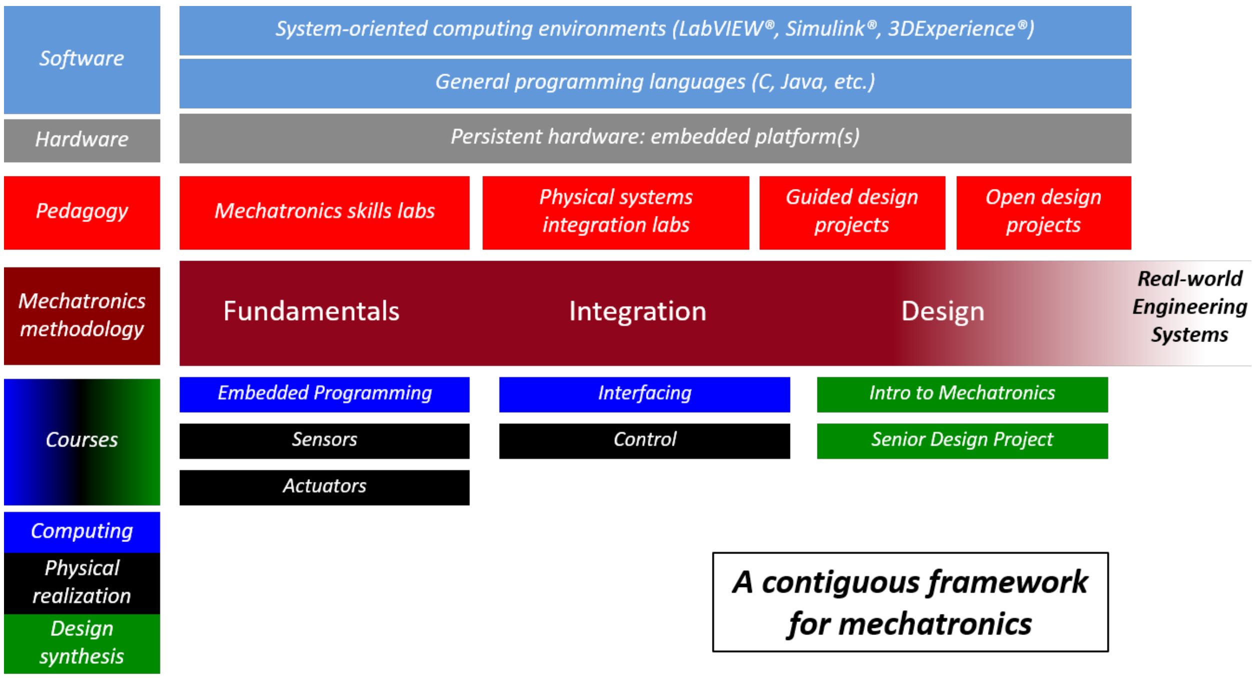
This discussion of the future of control courses in a mechatronics world is still somewhat narrow. A comprehensive perspective on mechatronics must involve an in-depth treatment of particular techniques and methodologies that have a functional intersection with conventional control. To this end, one of the active areas of development is the creation of a cohesive lab platform the traverses the entire mechatronics concept sequence that is inclusive of control.

Quanser QNET boards introduce students to engineering fundamentals.

This means that we need to develop meaningful lab experiences that encompass the complexity dimension: fundamental skills, to integration skills, to design skills, as well as mappings to the course structure – the core of sensors, actuators, and interfacing. Typically, courses that map to these concept introduce so-called hobby grade components and students receive a compact and, if they have some experience in hobby robotics, possibly familiar introduction to the topic. The Quanser approach is somewhat different.

Its line of QNET trainer boards that plug into the National Instruments ELVIS II instrumentation platform offers a “survey view” of these topics – i.e. take the students through a series of activities that introduce a large numbers of variations of respective components and techniques. But because the systems are designed around the efficient lab notion, students can work through this survey approach at a pace consistent with class time constraints.

The bigger picture is that students appreciate a greater range of options for more complex applications. Simplistic actuations of LEDs and motors can include brushed, brushless, servos, and solenoids; sensor types can span a broad range of physical variables;and important industry protocols such as CAN can be introduced in a meaningful manner.



In the end, the goal is that empowering students with an increased depth and breadth of the technological options as well as a tuning the perspectives on the foundational physical sciences will offer a stronger start to actual design in the capstone, internship, or industry experience.

From mechatronics to a modern view of ECE

The foregoing discussion is a prominent example of the general discussion in ECE circles on identifying a more modern and appealing image for the discipline in matters of recruitment and retention. A common remark is that when many Mechanical Engineering departments became the home of mechatronics, the computational and electronic methods and electric motor actuation that are traditionally ECE inventions, lost clarity.

The suggested focus on the physical systems in the mechatronics discussion is a concerted effort to rediscover the heart of ECE – that dimension in modern engineering that brings energy and "life" to engineering systems. The hope is that one can get the same thrill of hands-on building of mechatronics but in experiences that are consistent with the traditions of engineering science.

ECE Professor Derek Wright of the University of Waterloo in Canada is currently exploring the possibility of certain types of systems originally designed for control experiments to be applied to other courses. For example, with the right level of instrumentation and supplementary curriculum support material, core ECE courses such as power electronics, signals and systems, circuits, electricity and magnetism could receive some basic hands-on or physical demos to incrementally add an experiential dimension. More general courses such as differential equations, introductory computing, and numerical methods could also benefit in this way. The principal question to the instructor is, "Could you sacrifice part of one lecture week to try to illuminate the most essential idea in the course with a real physical system?" We start with this very modest step.

About the Author

Dr. Thomas Lee is Chief Education Officer at Quanser, a global company specializing in advanced lab systems for teaching and research in key fields such as mechatronics, control, and robotics. He is Chair of the ECEDHA Corporate Council. He also has adjunct faculty appointments in Systems Deign Engineering, University of Waterloo, Electrical and Computer Engineering, University of New Mexico, and Mechanical Engineering, York University.