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Building a Comprehensive Lab Sequence for an Undergraduate Mechatronics Program

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Motivation

The global engineering academic community is witnessing an explosive growth in the number of programs and courses in mechatronics. They take the form of options or electives within conventional departments, or as fully realized programs and departments. This is not surprising as society is inundated with chatter about the “Internet of Things”, robotics, drones, etc. Additionally, within the engineering profession, the computer control of complex engineering systems is now firmly entrenched in a principal framework for increasing the precision, performance, efficiency, and decreasing the cost of modern systems. Understandably, the mechatronics programs are part of the academic response to these trends.

While the core curriculum sequence of most undergraduate engineering programs is based on modeling and analysis of complex physical systems using mathematical and scientific methods, the mechatronics lab sequences remain problematically disconnected from this core.

Challenges

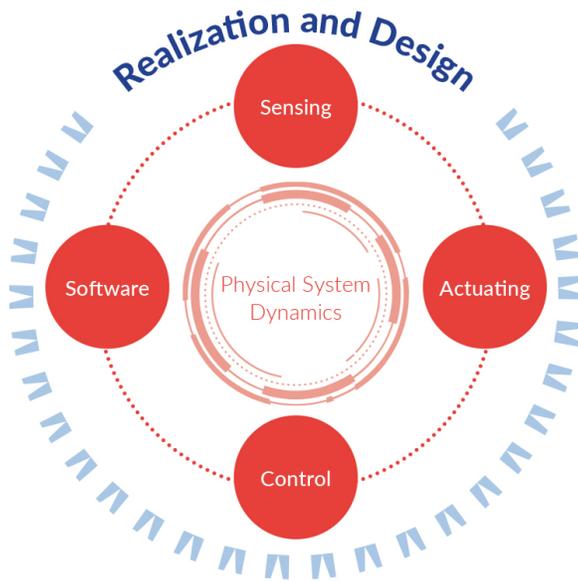
By its nature, a mechatronics program relies heavily on hands-on experiences and labs. Microprocessor programming, sensor integration, or hobby robotics are all very typical kinds of labs that many institutions have introduced. A common lab sequence sees students programming hobby microprocessor boards and then connecting them to simple sensors to operate small motors, lights, or other components. Because of the use of hobby-grade components, often the essential learning challenge becomes the programming as opposed to the system, in addition to the programming.

In many cases, the lab sequence culminates in projects where students might build small hobby robots to perform a relatively complex task. The challenge is again, typically in the programming to refine the smarts of the control software. The physical system itself remains relatively simple in configuration.

While the core curriculum sequence of most undergraduate engineering programs is based on modeling and analysis of complex physical systems using mathematical and scientific methods, the mechatronics lab sequences remain problematically disconnected from this core. Quanser’s contribution in this context is to offer a learning platform that reconciles the traditional applied sciences with modern mechatronic technique.



The Quanser Platform for Undergraduate Mechatronics is a unique technology platform that can take students from motivating first steps in mechatronics through to the building of skills proficiency, and prepare them to take on high fidelity mechatronic application and design challenges.



The Quanser Method focuses on the development of fundamental skills in a guided way that effectively prepares students to apply those skills in a more open-ended project and design context.

The Quanser Platform for Undergraduate Mechatronics

This article provides a summary of the rational framework that drove the design of Quanser's Mechatronics lab series of products:

- **Essential skills:** QNET Mechatronic Sensors, QNET Mechatronic Actuators, QNET Mechatronic Interfacing trainer boards.
- **Complex embedded applications and control:** QUBE-Servo 2 and Quanser AERO, advanced control plants with enhancements for mechatronic applications.
- **High level application-centric software frameworks.**

The Quanser Method for Mechatronics

The term Quanser Method refers to a core philosophy of harmonization of key concepts and techniques that are quite often treated independently in a curriculum sequence. For mechatronics programs, the Quanser Method focuses on the development of fundamental skills in a guided way that effectively prepares students to apply those skills in a more open-ended project and design context.

Additionally, the Quanser Method places significant emphasis on the inherent dynamics of engineering physical systems. In this way, the method differentiates itself from a programming-centric approach, and arguably is better at conceptually connecting to the majority of courses in typical undergraduate programs that are founded on engineering science, modeling, and mathematics.

Towards “High Fidelity” Mechatronics

The aim is to establish a skills framework for high fidelity mechatronic design – i.e. the conceptualization and realization of applications that exhibit dynamic fidelity and real-world relevance.

Dynamic fidelity is a fundamentally desirable attribute for educational applications. The majority of the courses within typical undergraduate curricula still stress the benefits of rigorous, modeling-focused analysis and design. Dynamic fidelity is the deterministic behavior of systems that suitably and consistently matches the descriptions within course theory. Ideally, the lab exercise should help make sense of the theory and not be seen as an alternative to the theory.

Relevance is a complex notion, and can range from systems that are end-applications themselves (e.g. a robot), or can be more abstract, but offer a motivating context when the system performs an action that is clearly challenging, but made easier through mechatronic methods (e.g. balancing an inverted pendulum).

Both of the above are a direct consequence of the central importance of the actual physical system, as opposed to a principal focus on programming, and in this way, the Quanser approach to mechatronics is clearly different from those based on hobby platforms.

The Quanser Method has resulted in a unique technology platform that can take students from motivating first steps in mechatronics through to the building of skills proficiency, and prepare them to take on high fidelity mechatronic application and design challenges. Uniquely, the Quanser platform offers an end-to-end perspective on the methodologies and workflows of mechatronics as outlined here.

Increase Application Complexity and Relevance

Severe time constraints in a course has historically meant that students could not surpass the most basic activities in a lab, as more complex or realistic examples would require steps and details of implementation that would prevent such exercises in a regular course. This is especially true when an institution bases its labs on hobby microprocessors or sensors/motors.

A principal philosophy in Quanser's technology platforms is to minimize implementation detail, so that students have a real chance to experience with some depth more interesting and relevant examples and exercises. The examples can move beyond the very basic to important applications involving high precision components with deterministic dynamics, industry-standard integration protocols, and human interface components such as keypads and LCD displays. Consequently, students do more and learn more without the time penalty that is demanded by hobby platforms.

The result is a unique sequence of products that take students from the very basic to advanced concepts and design.

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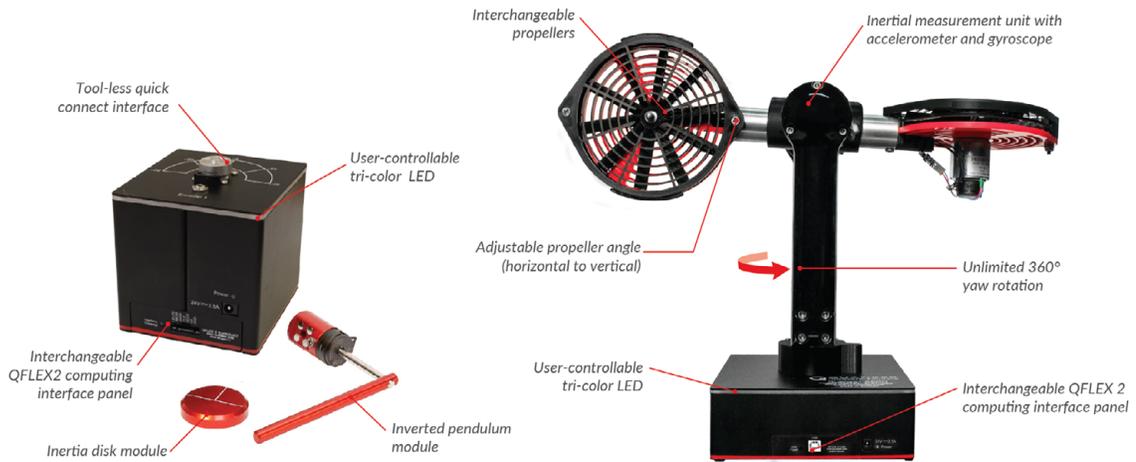
Essential skills for undergraduate mechatronics: Three trainer boards for the NI Educational Laboratory Virtual Instrumentation Suite (NI ELVIS) undergraduate lab platform cover arguably the most important technical hardware-focused skills in mechatronics: sensing, actuation, and integration (protocols). Uniquely, these products in their respective focus areas provide an engaging survey of common options and techniques. The sensor trainer includes over ten different sensors to measure; the actuator trainer surveys the most important classes of electric motors for mechatronics. The mechatronic integration offers students a chance to sample real applications and common protocols within a guided and well-scoped lab experience.

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Control of complex dynamics: The next step is to increase the complexity of the system and allow students to experience how modern engineering techniques can manage challenging situations. The control of complex dynamics is a key element here as it makes sense of the mathematics and modeling concepts introduced in the core course sequence and places these concepts in context of system design.

The latest generation of Quanser’s market-leading control plants offers unique adaptations to support a mechatronics focus in control. Quanser’s new QUBE-Servo 2 and Quanser AERO not only provide full support or conventional control but also are equipped with connectivity to microprocessors. Based on the Quanser QFLEX™ 2 framework, institutions can quickly switch from PC (USB) based control, or embedded control, via the Embedded QFLEX 2 panel for communications with common processor boards like Arduino™ or Raspberry Pi®.

Additionally, these features allow users to modify physical system configurations to add application complexity easily. The QUBE-Servo 2 has a unique magnetic coupling interface that lets you add custom dynamic components. The AERO’s rotors and links can be readily repositioned to support a broad range of flight-oriented experiments including helicopter



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

flight or even a form of quadcopter flight. In essence, these innovative plants are ideal for exploring complex dynamics and then going further with mechatronic control.

There is even an engaging LED light strip that responds with different colors based on input signals. Such a simple yet elegant feature is a great way to introduce state-based control logic – or simply to add a fun dimension to a control exercise.

Programming: The final dimension is the software experience. One of the biggest impediments to introducing meaningful system complexity into student labs is the programming effort in general languages like C. Quanser plants and trainers take advantage of industry-standard high-level system-design oriented computing environments including LabVIEW™ or Simulink®. Enhanced with Quanser software such as Quanser Rapid Control Prototyping (QRCP) for LabVIEW, or QUARC for Simulink, students work at the application and system level, and leave the details of I/O and implementation to the plug and play software. Combined with supplied courseware and additional resources available on-line, real applications and real complexity are now entirely within reach of undergraduate programs.

Related skills: The above describes the sequence for the core set of skills for mechatronics. Quanser also provides a range of products that offers engaging experiences in related applied sciences that help connect mechatronics concepts to specific physical system domains. For example, the Quanser QNET board for Physics and Dynamics is targeted at a broad range of mechanics. Strong intuition in such related applied fields is an important part of a comprehensive treatment of mechatronics.

Preparing for Engineering Complexity

The Quanser Method for mechatronics is, in essence, a preparatory sequence of experiences – they effectively provide the skills and insight through appropriately constrained, guided, and engaging exercises well-connected to the theoretical foundations. In many ways, however, this is incomplete. Quanser fundamentally believes that the learning sequence is not complete until a student directly addresses the real design challenges in the real world. This is the context of design projects.

Quanser believes that the approach described in this article is the ideal sequence for students to gain the necessary skills to do real design well in a senior or latter semester project. By surgically identifying key skill sets and illuminating and reinforcing these skills in motivating, engaging, and simultaneously rigorous ways, students reach a higher level of proficiency faster. They are ready for true engineering complexity.

About the Author



Dr. Tom Lee has been an active contributor in the global engineering and control systems community for over twenty years.

As Chief Education Officer at Quanser, a leader in real-time control and mechatronics solutions for education, research, and industry, Dr. Lee develops and implements the company's strategy for enriching and increasing the educational effectiveness of technology in the modern engineering education context. Prior to his appointment at Quanser, Dr. Lee was Vice President.

of Applications Engineering at Maplesoft, creators of the renowned Maple mathematical software system. In that capacity, he helped the company transform the mathematical technology to a complete engineering modeling and simulation solution.

He also serves as an Adjunct Professor of Systems Design Engineering at the University of Waterloo, noted for its leadership in engineering, computer science, and mathematics. Dr. Lee earned his Ph.D. in Mechanical Engineering at the University of Waterloo and his M.A.Sc. and B.A.Sc. in Systems Design Engineering at the University of Waterloo. He has published numerous papers and is a frequent invited speaker in the areas of engineering education, engineering modeling and simulation, and engineering computation.

Find more ideas and solutions from Quanser and National Instruments.

[Watch the Controls Teaching With myRIO and the Quanser QUBE-Servo Webcast](#)

[See How You Can Teach Controls and Mechatronics With NI ELVIS and Quanser QNETs](#)

About Quanser:

Quanser is the world leader in education and research for real-time control design and implementation. We specialize in outfitting engineering control laboratories to help universities captivate the brightest minds, motivate them to success, and produce graduates with industry-relevant skills. Universities worldwide implement Quanser's open architecture control solutions, industry-relevant curriculum, and cutting-edge work stations to teach Introductory, Intermediate, or Advanced controls to students in Electrical, Mechanical, Mechatronics, Robotics, Aerospace, Civil, and various other engineering disciplines.

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