AC 2007-1918: MENTOR GRAPHICS’ SYSTEMVISION SOFTWARE
CURRICULUM INTEGRATION

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Mentor Graphics’ SystemVision Software Curriculum Integration

Abstract

Dynamic system complexity is growing rapidly, creating the need for more powerful and complex control system design. It can be difficult to ensure that all students working within control system and mechatronic curricula develop an in-depth and complete understanding of the interaction between complex mechatronic systems and the control systems required to stabilize and optimize their behavior.

Due to this increase in system complexity, the need for time efficient yet accurate simulation and experimentation has become essential in dynamic system and control system design and development. Unfortunately, class sizes and lecture schedules have responded inversely and increased the difficulty in ensuring students have the breadth and depth of system analysis and control theory understanding and experience required of them by a demanding industry.

Mentor Graphics’ SystemVision software can improve the understanding and application of control theory, as well as complex dynamic system behavior in a reduced or compressed lecture schedule. SystemVision is a mechatronic and control system simulation package that includes the ability to abstract and simulate systems containing multiple technologies with complex interactions. This reduces analysis time and increases design accuracy by allowing the designer to abstractly determine accurate dynamic system behavior and simulate a control system design.

A great deal of lecture time can be spent working with the students to ensure a strong understanding of the analysis techniques required for even simple dynamic systems. By integrating SystemVision into dynamic system analysis, control theory and mechatronic course work, the students gain not only a more complete understanding of these basic analysis techniques and their results, but also observe and interact directly with the link between these basic concepts and the more complex dynamic systems and control systems the student is likely to see upon entering into industry.

We present the efforts of integrating Mentor Graphics’ SystemVision software into introductory system analysis and control theory as well as introductory mechatronic course work at Oregon State University. The successes, failures, and recommendations for further integration techniques are addressed.

1. Introduction

The complexity of dynamic systems students will face upon entering into industry is increasing quickly. Students must develop strong foundations in system analysis and control design to obtain an intuition for how these systems behave and how control can produce efficient methods of performing required system tasks. However, as system and control complexity increases outside of the classroom, care must be taken to ensure that classroom theory remains connected to the real-world application of these basics. Ensuring that the students come away from basic control theory or mechatronic course work not only with a solid understanding of the basics, but also knowledge of how to effectively apply the techniques can prove difficult.
Class size, lecture schedules and limited funding further complicate the development of this connection between theory and application. Specific to introductory control and mechatronic coursework; two extremes exist. Should the professor focus all lecture time on theory utilizing only abstract homework assignments, students will develop a sound understanding of the foundation and mathematics behind the analysis and design techniques, but almost certainly will lack acumen in regard to industrial applications. This method certainly benefits lecture schedules as it allows the professor ample time to present the wide range of topics that typically form the foundation of control theory and mechatronics. Additionally it is the best option for a limited funding situation, as students require few external resources.

Alternatively, a course laboratory section can be developed, requiring students to spend a specific amount of time external to the lecture hall applying theory to real-world, physical, problems. This provides the best opportunity for the students to prepare for applications encountered in industry. However, it may also require that the professor spend a significant amount of lecture time providing supplementary education for the laboratory experiments. This can strongly affect the course lecture schedule and may result in eliminating subject matter from the lectures entirely. The costs associated with creating and maintaining a laboratory filled with the equipment and hardware required for large class sizes and engaging applications can be very large as well. Both extremes have their benefits and detriments, therefore, preferentially the situation would be a carefully chosen compromise between the two.

A tool is needed for introduction into the course curriculum that can develop a strong theoretical foundation for students, maintain the conceptual connection of theory to real-world application and provide practice in doing so. The tool must have a shallow enough learning curve such that the professor and students can be productive in a reasonable amount of time.

In our search for such a tool to integrate into our introductory control theory and mechatronic coursework we approached Mentor Graphics, a higher education partner the College of Engineering at Oregon State University (OSU). Mentor Graphics Corporation is a leading supplier of electronic design automation tools. The Higher Education Program at Mentor Graphics brought to our attention their SystemVision product. SystemVision is a mixed-signal modeling and simulation environment that acts as a virtual lab for the design and analysis of distributed mechatronic systems.

The paper is structured as follows. A description of the courses the software was integrated into is presented in Section 2. Section 3 describes the SystemVision software in more detail, and the expected fit with our needs. Details of the integration methods and results are presented in Sections 4 and 5, respectively. We provide recommendations for improving integration of the SystemVision software into the curriculum in Section 6 and draw conclusions in Section 7.
2. Course Descriptions

We found there to be two potential impediments to integrating these increasingly complex dynamic systems requiring control into the curriculum. First, systems complex enough to be pedagogically interesting inevitably require control systems in order to ensure accurate and reliable task execution. However, these control systems contain enough complexity in themselves that an abstraction of the dynamic system under scrutiny is required in order for proper exposure of the requisite control theory underlying the solution. The abstraction cannot be taken to too high a level however, as the students may lose a conceptual understanding of the intimate connection between the control system and the system under control.

Second, these systems are tasked with progressively complicated behaviors, requiring the integration of multiple technologies for efficient task completion. System interactions in these instances inherently require interdisciplinary knowledge of the dynamics of mechanical, electrical, thermal, and fluidic systems. The interaction of these technologies clearly cannot be ignored, but can prove difficult to expose to students in an introductory fashion.

2.1 Dynamic Systems and Control

This upper-division undergraduate course, offered to mechanical and electrical engineering majors, covers introductory system analysis and dynamics for linear first- and second-order systems and second-order approximations of higher order systems. It also covers introductory single-input, single-output control system design for the PID superset of compensators.

Here a tool was required to abstract a real-world multi-technology system to illustrate the importance of time and frequency analysis, as well as basic control theory, while maintaining the connection to the physical system intuition students had developed in previous courses. For example, in analyzing the dynamics and control of a DC motor, from developing the equations of motion to performing root locus or Nyquist analyses, the students were observed to quickly lose comfort in what actually was occurring or why it was important.

Therefore, the tool needed to enable the student to visualize the dynamic system in a familiar manner, while analyzing it in a way pertinent to the concepts of control theory. It also had to provide analysis techniques that yielded a direct connection between the internal system components and their importance with respect to the control system design. For instance, in the DC motor example, how does motor rotor inertia contribute to step-input overshoot?

2.2 Introductory Mechatronics

This upper-division undergraduate course, offered to mechanical and electrical engineering majors, covers introductory mechatronic concepts including basic electrical circuits and components, both analog and digital. It covers the performance and integration of a wide range of sensors, data acquisition techniques, and common actuators in electromechanical systems, therefore providing students with an introductory understanding of electromechanical system relationships and interactions.
For this course, we required a tool that allowed students to not only visualize and study the individual behaviors of each technology in a multi-technology dynamic system, but also their intricate and occasionally unexpected interaction behavior. The tool needed to easily enable both analyses of individual component characteristics as well how component characteristics contributed to the interaction with another piece of technology to produce the overall system behavior. For example, what relationship does the pitch of a lead screw have to the current into the motor driving the system?

Therefore the tool needed to allow for the progressive development of a real-world multi-technology model over the duration of the course so that each separate technology could be analyzed first in isolated detail, and then categorically combined with other technologies culminating in a full dynamic analysis of the system. This would help prevent students from losing a strong understanding of individual component behavior while developing their intuition for technology interaction in these complex dynamic systems.

3. SystemVision

We determined that the tool best suited for the previous tasks was Mentor Graphics’ SystemVision software. SystemVision is a mechatronic simulation package which provides for the design and analysis of distributed multi-technology systems. It supports three widely utilized languages in industry: VHDL-AMS, SPICE, and C. SystemVision also contains a large set of prepackaged industry standard models of components commonly encountered in industrial systems.[1],[2]

Schematic capture methods of model development allow the system designer to break the system into behavioral blocks for isolated analysis, or combine them into a single block for analysis of global system behavior. In control system design, this structure allows for an abstract functional block diagram of a control system to be connected directly to a more specific multi-physics model of a plant and simulated in real-time.

For use in the educational environment, the software enables students to visualize the dynamic system in a familiar way, while performing the time and frequency analysis required of a control system designer. Control system design can proceed in an abstract manner, utilizing concepts provided in lecture and simulated directly with the model, allowing the student to directly visualize the effect the control system has on the system output. Returning to the DC motor
example discussed previously in Section 2.1, students could simply change the motor rotor inertia by 10% to promptly visualize the effect motor inertia has on the overshoot of the system output.

By separating the control system into functional blocks, the student can also quickly consider the effects individual components have on the system compensation. For example, the student could visualize the output of the integrator in a PID compensator simultaneously with the current going into the motor. In this way, students can make a more direct conceptual connection with system interactions.

This lends itself well to intricate analysis of the individual technologies in a multi-technology system. By progressively installing each technology into a system model and performing analyses, the unique and independent behavior of a specific technology can be understood in tandem with the interaction and effect it has on the system as a whole. For example, in a motor / leadscrew / hydraulic cylinder system, the motor and voltage source can be examined in detail first to understand the internal electromechanical characteristics, followed by the rotational to translational force conversion that occurs with the leadscrew, and finally the translation to pressure production and force conversion that occurs within the hydraulic cylinder.

This can all be done while maintaining a simple and easy to understand visualization of the system. Therefore, a conceptual understanding of the dynamics at work can be maintained, while the underlying mathematics and theory of operation of each piece of technology, and the system as a whole, can be examined in detail during course lectures.

4. Integration

While the two courses chosen for curriculum integration of SystemVision are closely related conceptually, we determined that there were two distinct methods by which the software could be utilized: a computer-aided design (CAD) project or categorical integration into homework assignments. We sought to integrate and observe the results of these two methods separately by utilizing a single method for each course. The system dynamics and control course already contained a well structured CAD project utilizing MATLAB exclusively, and was therefore chosen for reformatting into a SystemVision based project, whereas the introductory mechatronics course was chosen for homework integration.

4.1 CAD Project

The CAD project of the system dynamics and control course was separated into five installments. Each installment was designed to illustrate concepts presented in lecture while simultaneously leading the student progressively through the analysis of a complex dynamic system and the control system design required to perform a predetermined task. Installments were generally constructed as follows:

1) Analyze the primary dynamics of the system by developing a system block diagram and determining the subsequent input-output transfer function.

2) Simulate this system transfer function in MATLAB and examine the time and frequency response of the simplified equations of motion.
3) Use SystemVision to create a schematic based model of the above system and perform the same time and frequency response, considering possible causes for difference in the two sets of analysis.

4) Utilizing the information obtained from the system response and concepts presented in lecture; analytically design a control system of the students’ choice.

5) Implement the control system in the SystemVision model, analyze the controlled system behavior, and tune the control system to meet a specific set of customer requirements for the task at hand.

Each term a different system and task has been chosen as the class project. One term the students worked with a model representing a simplified version of an electronic traction control system developed for use on the OSU SAE MiniBAJA design competition [4]. The model consisted of a DC motor applying force to a standard automotive braking system via a leadscrew. The students were required to complete all the above installments; finally designing and simulating a control system to produce a specific pressure within the system, obeying specific temporal specifications.

4.2 Homework

For homework integration in the mechatronics course, individual problems were selected for completion utilizing the SystemVision software. Each assignment, though not directly related to the system utilized in the final exam, was designed to expose the student to a specific technology and analysis technique that would ultimately prove useful in the course’s take home final exam.

The final exam consisted of an XY stage for use in the steel manufacturing industry. The students were required to choose the motor parameters, leadscrew pitch, encoder density and data acquisition details based on provided material and process loads as well as acceleration and steady-state process requirements. Each pertinent homework assignment over the course of the term contained analysis of individual system technologies in SystemVision. For example, basic analog electric circuits were simulated, followed by digital circuits, culminating in simulating DC motors with leadscrews and process loads. The homework assignments were required to be done in SystemVision; however the student was given the choice on whether to utilize SystemVision for the full system analysis and component selection.

5. Observations

While integration efforts continue in both courses, we have obtained qualitative observations, in the form of professor and teaching assistant notes and student comments, regarding the successes and failures of both methods. Positive feedback from all sources is compiled into observations listed in this section. Negative feedback is compiled as a set of recommendations presented, along with potential methods to obtain more detailed quantitative results for the integration of SystemVision into course curriculum, in Section 6.
5.1 CAD Project Results

By providing the students with a tool that facilitated complex dynamic system abstraction, the professor surveyed was able to bring theory presented in lecture closer to its application for the students without sacrificing a great deal of lecture time. In this way the students appeared to be able to gain a solid understanding of control theory without abandoning the intuition they have built regarding physical system behaviors.

SystemVision allowed the surveyed students to more easily apply the theory presented in class to a more detailed physical representation of the dynamic system at hand. This was done by utilizing the extensive library of industry standard models provided with the software package. Though the power of SystemVision lies with the VHDL-AMS language, these provided models appeared to allow the students to quickly build and simulate more realistic, and applicable, dynamic system models than can be detailed in class, without the need for a background in any specific modeling language. This, in conjunction with the analysis tools the software provides, largely reduced the amount of time the surveyed professor spent in class describing the application, as the students appeared to more quickly determine system and control behavior and relate it to course concepts then observed in previous terms.

Specific to the CAD project, the majority of the students surveyed indicated that the inclusion of SystemVision improved their understanding of the application of control systems in an industry specific domain. They indicated that the early installments of the project helped them see the conversion from equations of motion to control theory analysis, while the latter installments helped visualize and relate these analysis techniques back to physical system behavior. Most felt the project utilized the strengths of both MATLAB and SystemVision to increase their understanding of the material presented and that further experience with the tool would reduce the amount of time spent on control system design. [5],[7]

5.2 Homework Results

While SystemVision provided a means to abstract complex system behavior to a specific level in the dynamic systems and control course, it also provided a way to analyze individual pieces of technology in a complex dynamic system for the mechatronic course. The large library of detailed and accurate models present in SystemVision enabled the surveyed professor to focus on how to utilize the wide range of technologies available in mechatronic system design without consuming large quantities of lecture time demonstrating and analyzing their behaviors.

By integrating SystemVision into the homework assignments, the students surveyed felt they were able to promptly and accurately simulate a piece of technology introduced in the course and analyze in detail not only its overall behavior, but the internal functionality as well. Once this was done, the students appeared to combine these technologies into a larger system and analyze the intricacies of the interaction with little effort. This lent strong support to the topics discussed in lecture and freed the professor to discuss a greater range of subject matter.

Specific to the homework assignments, the students surveyed expressed that they had acquired a deeper understanding of the interaction between electronic and mechanical technologies in
complex dynamic systems. The majority appreciated the ability to utilize only one tool to model and simulate the entire mixed-technology system in a straight-forward fashion, without the need to completely evaluate all equations of motion from all subsystems. Many students expressed excitement regarding the ability to simultaneously review global and internal behaviors in complex systems.\footnote{\textsuperscript{6,8}}

6. Recommendations

From these observations, we present a set of recommendations for improving the SystemVision software integration into engineering curriculum. As well, suggestions for a more quantitative assessment of the tool’s effectiveness in improving student learning are addressed.

6.1 CAD Project

- Adopt the method of integrating SystemVision into individual homework assignments with simple examples of each technique required in the project. This will reduce the learning curve encountered by the students when the project is first assigned, and establish an understanding of the tool’s application early.
- Alternatively, the core SystemVision model of the system to be analyzed for the project may be provided to the students. In this instance, students will make modifications based on customer requirements, such as component choices from common manufacturers. In this way the students can focus more closely on the behavior required of the plant and control system together without sacrificing an understanding of how the system itself behaves.
- Create a physical model of the system that the students, at their leisure, interact with as they iteratively analyze it using the CAD tools present in SystemVision. After completing the control design, implement it in the physical system and require analysis of the resultant physical behaviors.\footnote{\textsuperscript{5,7}}

6.2 Homework Assignments

- Expand student requirements regarding each assignment. Rather than simply performing simulations, require a discussion of the results as they related to the text or lecture.
- Adopt the method of integrating SystemVision into a course project by requiring some level of simulation results regarding a student’s final design project. As a result, the students utilize the tools available to them to improve project success and education value.\footnote{\textsuperscript{6,8}}

6.3 Assessment

- If a course is offered more than once per academic year, select one section to include the software integration, and one section to remain as it was. Compare and contrast project grade distributions. From this, a control group is established based on solid historical data regarding project grade outcomes.
- Give Pre- and post-tests in the course and gain scores utilized to analyze the students educational gain with and without the software integration.
- Indicate to the students at the beginning of the term that they are participating in a trial integration of the software and perform directed student surveys.
• Determine which students are pursuing careers involving significant work with control systems and attempt directed surveys after a grace period employed after graduation.

7. Conclusion

In this work, we analyzed how the integration of the Mentor Graphics SystemVision software package could improve student learning of both theoretical and practical control system and mechatronic design. Integration of the software package into dynamic systems and control and introductory mechatronic curriculums qualitatively was shown to successfully provide the bridge needed by students between theory and application of this material.

After selecting and implementing two distinct integration methods, our experiences indicated that a mixture of both course projects and sequential homework assignments would prove to be the most effective utilization of the educational value of the tool. Students applying both methods expressed a unique and engaging educational benefit from the curriculum additions made possible through the use of the software.

We found that integration of the software allowed the professor to spend an increased amount of lecture time on theory and mechanics without having to abandon a conveyance of the techniques required in application of the material to real-world problems. Since large computer laboratories are available at most engineering schools, use of the software is accommodating to large class sizes. Finally, utilizing higher education site license benefits of the software as well as educational versions available freely to the students kept resource costs for supporting the coursework to a minimum, while improving student learning.

8. References


