Evolving Technologies and Trends for Innovative Online Delivery of Engineering Curriculum

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***Abstract*—For more than a decade, engineering educators have been exploring innovative way to use the internet to improve engineering education. With a renewed emphasis on active learning, and a drive to provide more affordable access to textbooks and curriculum content globally, engineering educators have turned to the promises of the internet for solutions to these challenges. These solutions have taken the form of online content repositories and authoring tools for providing innovative curriculum to thousands of individuals and schools, as well as virtual and remote laboratories that bring the promise of active learning to a wider variety of students. This paper discusses the new trends and technologies under development to help fulfill the promise of the internet in revolutionizing engineering education.**

***Index Terms*—Virtual Laboratories, Remote Laboratories, Online Software Technology, LabVIEW.**

I. Introduction

Current techniques to advance online computer-based engineering education can be classified under four groups: computer-based training, computer-assisted learning, computer-assisted instruction and computer-assisted experimenting [1]. Several factors are adding to the advancements in this area, including a desire to increase active and discovery learning [2], a desire to make laboratory facilities available to the wider community, and the need to address the central problem of providing students meaningful, relevant, and up-to-date practical experiences under the limitation of finite resources such as laboratory hardware and infrastructure in addition to common logistical, organizational, and cost concerns [1] [2]. Although a number of systems and solutions have been developed over the past decade, new technologies under development by both educational institutions and private software and hardware vendors are addressing the many limitations of these early solutions by introducing tools for content sharing and globalization, interactivity, as well as low-cost, easy to use and develop software. This paper discusses a revolutionary new means of authoring and delivering online engineering curriculum that addresses the first two groups listed above (computer-based training and computer-assisted learning), as well as new technology under development from National Instruments that addresses the latter of the two groups listed above (computer-assisted instruction and computer-assisted experimenting).

II. Online Curriculum Development

One of the greatest promises the internet has fulfilled over the last decade is an almost unlimited access to information for individuals almost anywhere in the world. Several projects in development over the last several years attempt to extend this access to information to high-quality curriculum from leading educational institutions worldwide. The MIT OpenCourseWare (OCW) initiative is one example of such a project. Officially launched in 2001, MIT's OCW provides free, searchable access to virtually all of MIT's course materials for educators, students, and self-learners around the world. The vision of the MIT OCW initiative is to create a vast network of universities around the world offering open access to high-quality educational materials, and recently six major universities in Japan announced similar OCW initiatives. To date, more than 1000 courses from MIT have been published as a part of their OCW initiative. Course content includes a variety of different media formats, including PDF files of lecture notes, quizzes, and exams as well as a number of video and audio clips of recorded lectures [3].

The trend of making scholarly material available online for free has even caught the attention of private industry. In December of 2004, Google announced plans to digitize and make available online thousands of volumes of books currently available in leading libraries at institutions such as Harvard, Stanford, and the University of Michigan [4].

These efforts, and other similar ventures, are by all measures relevant and important; however their singular purpose as content repositories do not fit well under any of the four techniques, introduced above, for advancing online computer-based engineering education. A new trend that extends beyond the ideas behind the OCW initiative that actively addresses computer-based training, computer-assisted learning, instruction, and experimenting is under active development at Rice University.

A. Connexions

The Connexions Project (http://cnx.rice.edu/), launched at Rice University in 1999, is an open-source/open-access online environment for collaboratively developing, freely sharing, and rapidly publishing scholarly content on the Web. In contrast to other online curriculum repositories previously mentioned, Connexions exists to allow educators from around the world to author content collaboratively, greatly expanding the impact on engineering education that only an empowered community of educators can provide. It accomplishes this through a variety of open-source software tools and technologies which use the internet as a publishing mechanism, as opposed to the OCW model of posting pre-written PDF and other files online for users to download. With this model of online publishing (which uses XML) educators can perform real-time editing and derivation of works, meeting the demands of engineering education where rapid advancements in technology and innovation necessitates more efficient and flexible means of accumulating the latest know how and updated information [5].

Inspired by parallel developments in the open-source software world (the Linux operating system, for example), Connexions seeks to provide free access to quality teaching materials that are amenable to customization and personalization to match local contexts (language, level, etc.). Moreover, Connexions seeks to link and empower local educators in a global community that can efficiently and benefit and propagate the materials.

Befitting its name, Connexions has two primary goals:

• To convey the interconnected nature of knowledge across disciplines, courses, and curricula;

• To move away from a centralized, solitary authoring, publishing, and learning process to one based on connecting people into global learning communities that share knowledge.

A fundamental aspect of Connexions is an emphasis on free content that is open-licensed to facilitate sharing, easy reuse, and easy recontextualization. In combination with powerful software tools, Connexions gives learners of any age free access to knowledge materials that can be readily manipulated to suit their individual learning styles as they explore links among concepts. The free software tools also foster the development, manipulation, and continuous refinement of the materials by diverse communities of authors and teachers.

Starting with an initial proof of concept, Connexions has been under intense development and is beginning to attract the attention of a growing number of concerned educators worldwide. Its hallmarks include:

• A Content Commons of diverse educational materials spanning the knowledge continuum, which are modularized for easy reuse and available free-of-charge to anyone in the world;

• Visualization and navigation of the "Connexions" among concepts, courses, and curricula;

• High-quality materials, thanks to an iterative development process and an inherent quality assessment mechanism;

• Rapid, collaborative authoring of the materials by global communities of authors;

• Flexible, dynamic construction of an infinite variety of customized courses and curricula enabled by a coherent format (XML) and delivered in a variety of forms, from Web pages to e-books to paper texts.

• Multilanguage capability to support diverse audiences;

• A coherent intellectual property (IP) framework based on the Creative Commons open-access licenses.

B. Software Technology Advancements

In their efforts to meet the demands discussed above and create effective Web-based curricula alternatives, educators are looking for ways to speed and simplify the development of rich multimedia content for their curriculum modules. National Instruments, a leading educational partner and tools provider based in Austin, Texas, is investing significantly in its products to address the needs of engineering educators worldwide.

Specifically, National Instruments is developing a new technology for its flagship and industry-standard software development environment, LabVIEW, which will help educators enhance their online curricula. With this new technology, best described as a LabVIEW plug-in for Web browsers, currently under development and testing with the Connexions project, educators can create interactive simulations and demonstrations that can be directly embedded into their curriculum modules and viewed using any conventional Web browser. See Fig. 1 for an example showing a live LabVIEW program embedded into a Connexions module. Compared with existing means for delivering interactive demonstrations through online curricula, which often involve time-consuming and costly development with general-purpose programming environments such as JAVA, the approach based on LabVIEW, has several advantages [6]:

1) *High efficiency*. With the use of the LabVIEW graphical programming language, extendable libraries, advanced debugging features, and intuitive graphical user interface (GUI), developers spend anywhere between 4 to 10 times less time developing applications than using traditional text-based languages [7].

2) *High Expandability.* The abundant libraries embedded in LabVIEW, in addition to extensible interfacing to other development tools such as C, MATLAB, and the Windows API allow for easy expansion to meet new challenges or add functionality. Additionally, the modular software development model of LabVIEW allows for the addition of new functionality within existing frameworks.

3) *Independency and flexibility*. Taking advantage of standard HTML and XML architectures, the new LabVIEW plug-in capability becomes independent of the user's operating system and Web browser.

4) *Multithreading safety.* The new architecture of the LabVIEW plug-in allows a virtually unlimited number of users to access and interact with the same module of online curriculum content and associated interactive demonstration.

III. Remote and Virtual Laboratories

Distance learning has taken on many forms and meanings for more than a quarter century. Early techniques for distance learning involved printed materials, including tutorials, assignments, and exams, passed between student and educators through the mail in order to complete course credit. Over time, this experience was enhanced through the use of other media including radios, television, audio and video tapes, and the telephone. Current practices are incorporating the internet to bring multimedia interaction to students everywhere, anytime, in real time.

Remote and virtual laboratories are two effective techniques for the use of the internet in engineering education, previously introduced as computer-assisted instruction and computer-assisted experimenting. Specifically, the software involved in creating such online laboratories either allows a user to interact with an experimental setup located in another geographical location (i.e. a remote laboratory) or uses numerical simulation tools to emulate the behavior of experimental system (i.e.a virtual laboratory) [2].

Educators create these online laboratories to help students acquire hands-on laboratory experience without requiring physical access to a building with specific experimental equipment [2] [8]. Their appeal is largely due to the increasing demand for active learning and flexible education, and for the appeal of implementing techniques of learning via discovery.

Active learning seeks to provide students with opportunities to better integrate and reinforce knowledge presented in the classroom, as well as to acquire the practical know-how that is an essential component in engineering education. Problem-based learning and hands-on laboratory activities are good examples of active-learning vehicles. In traditional educational settings, the realization of an effective active-learning environment calls for intense levels of interaction with experimental resources, and requires the coordination of the efforts and schedules of multiple parties, including numerous students and pedagogical support staff.

Virtual and remote laboratories offer substantial flexible education benefits because students can access them at any time and from any location, features that traditional learning environments cannot easily match. In addition, educators can supplement traditional teaching methodologies with virtual and remote-control laboratory tools. For example, they can be used during a traditional lecture to show students how to apply concepts presented in class to a simulated or remote experimental system. This approach imbues a classical lecture with an active and flexible learning component, thus strengthening the pedagogical value of the lecture.

Another benefit of virtual and remote laboratories in education is that they promote discovery learning. In this approach students are given access to the laboratory with minimal instructions and can explore the systems for themselves. A virtual laboratory or a well designed remote laboratory can offer students a chance to safely explore the behavior of a system that may be physically inaccessible [2].

IV. SOFTWARE TECHNOLOGY FOR ONLINE LABS

LabVIEW has long been recognized as the software of choice for implementing online laboratories in engineering education [1] [2] [5] [6] [9]. For years, internet technology available in LabVIEW, including the Internet Developers Toolkit, a built in LabVIEW Web Server, a Web Publishing Tool, and Remote Front Panel technology, combined with built-in and easy to develop intuitive GUIs specifically designed for engineering applications, made LabVIEW a standard for online laboratory development.

Development in LabVIEW for both types of online laboratories, remote and virtual, is similar, and typically is built using a client/server architecture. This architecture is generally written in either a simulated virtual laboratory format, or a remote instrument sharing or remote control format. With the simulated virtual laboratory format, the server shares local simulation software and returns experiment results back to the client. This implementation is entirely simulated and does not interface with actual hardware. The remote instrument sharing or control laboratory replaces simulation with calls to actual hardware. In this architecture, the client sends control commands to the server, which schedules and processes the commands and returns data back to the client upon completion [6].

A. Remote Laboratory Software Development

Developing a remote laboratory, one in which a user is allowed to interact with an experimental setup located in another geographical location, provides many challenges to an educator. The difficulty of timing and control of remote instrumentation combined with necessary scheduling of multiple users has plagued educators for some time and is the subject of many papers. However, many successful applications have shown that using one single development environment, oftentimes LabVIEW, to address these challenges can make for a successful implementation of virtually any remote laboratory [1].

LabVIEW's built in instrument connectivity, including over 4,000 instrument drivers from more than 200 vendors provides educators an efficient means to add computer connectivity and control to their existing instrumentation systems. Combine that with built in tools for a wide variety of NI data acquisition boards, modular instruments, image acquisition devices, and motion control technology, and educators have access to myriad of I/O hardware, easily controlled and presented through a single, easy to use software development environment.

The tight integration between LabVIEW and high-performance, low-cost hardware has always been a hallmark reason for using LabVIEW in the laboratory. However, new developments to the LabVIEW platform, including Remote Front Panel and Web Publishing tools, are the enabling technologies that allow educators to easily develop and publish their remote laboratories. With these standard features of LabVIEW, an educator can quickly publish the front panel of any LabVIEW program for use in a standard Web browser. Once published, anyone on the Web with the proper permissions can access and control the experiment from the local server [10]. For remote laboratories, this tool creates one hypertext instance that can be accessed by one student at a time using a Web browser. The ability to allow multiple users full access to the remote laboratory can be accomplished by creating a common gateway interface (CGI) front end and scheduling procedure, all within LabVIEW, if desired. Different techniques for implementing CGI and scheduling procedures can be found in [2] [5] [6] [9].

B. Virtual Laboratory Software Development

Software development for virtual laboratories is very similar to that of remote labs, with the replacement of the hardware control with software simulation. LabVIEW's built-in tools for GUI design, coupled with recently released tools such as the LabVIEW Simulation Module and 3D Picture Control toolkit (for both 2D and 3D animation) make presenting intuitive virtual labs to students powerful and easy to develop. The new LabVIEW plug-in technology, currently under development and mentioned previously for use with Connexions, also simplifies the implementation of virtual labs by removing the need to implement a separate CGI to allow multiple user access. This technology also eases the restriction of bandwidth problems, as the actual simulation programs is downloaded and run locally on the student's machine. See Fig. 2 for an example of a Virtual Control Laboratory developed using LabVIEW. For detailed information on virtual lab implementation, see [2].

V. Conclusion

New developments in technology such as the Connexions project and innovative software technologies such as NI LabVIEW are increasingly allowing engineering educators to meet the demands of providing rich, up to date engineering content and laboratories online. Now more than ever, educators are empowered and enabled to create the kind of custom online engineering modules that offer the type of pedagogical scenarios that only the internet can enable.

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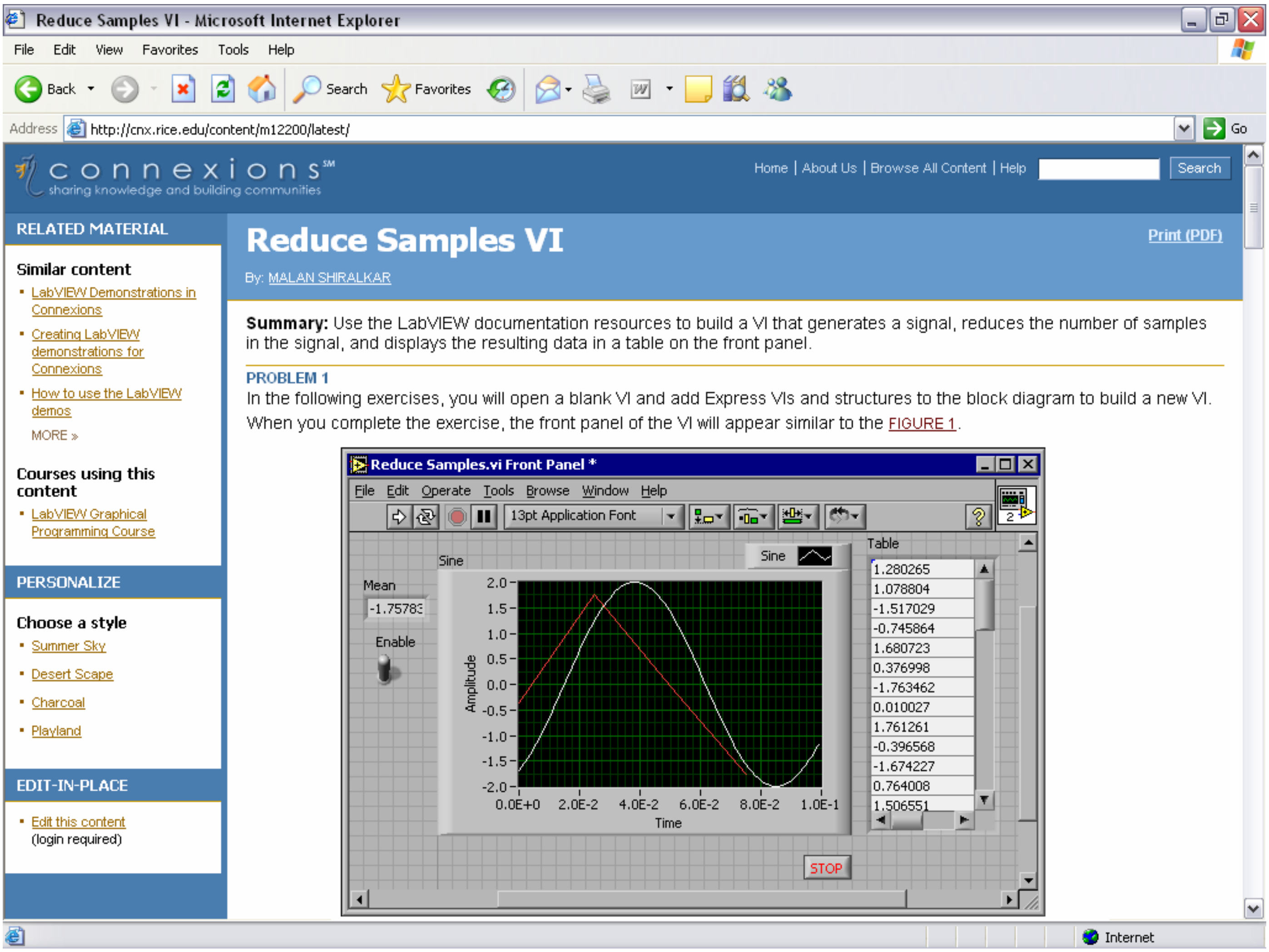

Figure 1. Example of a live LabVIEW simulation embedded in Connexions

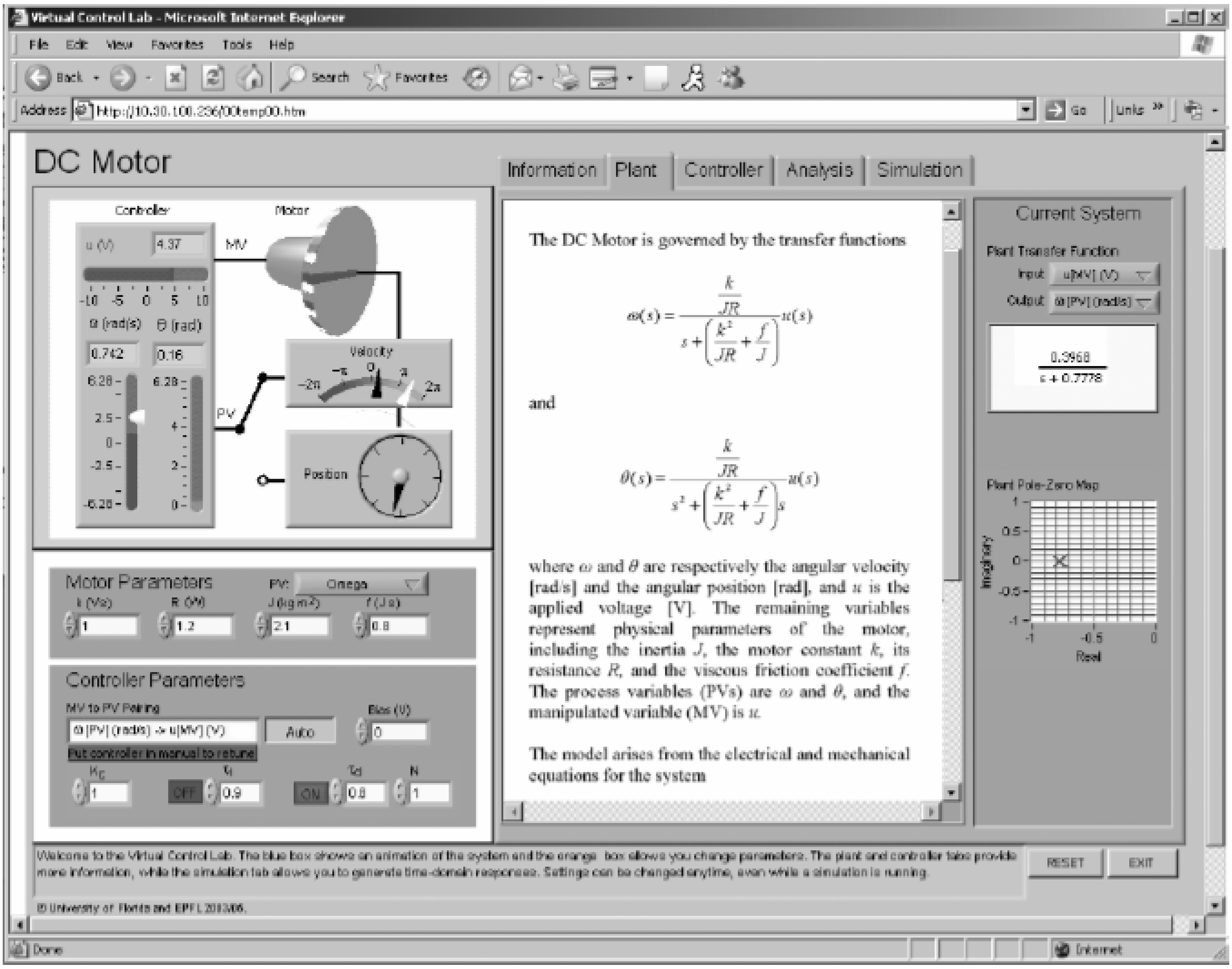

Figure 2. DC Motor Virtual Control Lab developed in LabVIEW and accessed by students using a standard Web browser [2]