Motivations for a Distributed Virtual Laboratory for Continuous Manufacturing Education and Training

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Abstract

This paper presents motivations for and potential benefits of a distributed virtual laboratory for manufacturing education. The distributed virtual laboratory we describe here integrates a contemporary computer-based training delivery system with emerging open information systems, simulation, and visualization methods to form a distributed, architecture-independent, interactive experiential learning environment. We discuss our virtual laboratory concept in the context of recent developments in Internet-based distance learning by engineering educators, and describe a case-study in which the virtual laboratory is used to present a short-course for a Pittsburgh-area industrial engineering firm. We conclude by discussing an information system framework for our implementation of the virtual laboratory.

Introduction

The virtual manufacturing laboratory proposed here integrates a contemporary computer-based training delivery environment with emerging information systems, simulation, and visualization methods to form a distributed, architecture-independent, interactive experiential learning environment. We expect that implementations of a distributed virtual manufacturing laboratory may be used by various agencies to provide continuous training and education in value-adding, manufacturing-related domains. In the next sections, we review background issues that motivate this research.

Background

In its report on information technology for manufacturing, the National Research Council's Committee to Study Information Technology and Manufacturing called for a wide ranging research agenda that included investigations into tools and techniques to help enterprises and individuals understand and manage the rapid changes they are expected to face.[1] The committee identified the need for better means of educational delivery to facilitate the renewal and currency of employee knowledge in manufacturing enterprises. They suggested that intelligent tutoring systems, long-distance learning systems, and multimedia experiential learning tools might be appropriate mechanisms for delivering "just-in-time learning" to the manufacturing domain. The committee concluded that multimedia and virtual reality technologies offer promise for "providing a flexible, socially acceptable, and nonthreatening interface for educational and skill-building programs."

A wide range of communication technologies have been used by education and training providers since the early 1960s to deliver continuing education and degree programs to engineering professionals at or near their workplaces. The technological constraints of traditional delivery methods limited these offerings to seminar and lecture-based courses. The lack of significant "hands-on" laboratory experiences in the vast majority of distance learning-based engineering programs has been cited as a potential factor in negative reaction of students toward these programs. Learning style research suggests that individuals engaged in engineering-related activities, including manufacturing, tend to emphasize a learning style preference for active learning environments.[2] This implies that instructional methods that facilitate active learning and experimentation through the use of high-fidelity simulated, or virtual, systems should be preferable to more reflective instructional methods.

In the next section, we consider further the motivation for a distributed virtual manufacturing laboratory for continuous training within the context of a specific manufacturing knowledge domain.

Continuous Education and Training for Manufacturing

Recent reports in the popular press continue to underscore the importance placed on continuous training by many industries. In June 1997, we conducted an informal telephone survey of manufacturing engineering technology educators to assess reaction to, and potential demand for, a proposed virtual manufacturing laboratory that would be accessed via the World-Wide Web. We found that in all but one instance, a general purpose environment for manufacturing automation of sufficient fidelity would be useful to augment existing physical laboratories. Following this first investigation, we initiated proof-of-concept development for an Internet-based virtual manufacturing laboratory that could provide the opportunity for future commercialization. An initial task of this development project focused on the selection of a relevant knowledge area within the manufacturing systems engineering domain that would act as the virtual manufacturing laboratory's case study. Our assessment of several candidate knowledge areas suggested that focusing our case study on the field of *work measurement* could meet our objectives. A recent commentary by Rauglas suggests that work measurement remains a crucial function of the industrial engineering cycle, offering support for our decision.[3] He reports that the Society of Manufacturing Engineers has committed itself to the continuing education and training of practicing manufacturing engineers in topics considered traditionally within the domain of industrial engineering, *e.g.*, work measurement.

The Pittsburgh-based industrial engineering firm H.B. Maynard and Company provides consulting services to a diverse range of industries. The firm also develops and markets intellectual, software, and training products based on the work measurement methodology *Maynard Operation Sequencing Technique* (MOST), advanced by Zandin in the late 1960s. We were invited to examine Maynard's training organization for opportunities to employ a virtual laboratory-enhanced computer-based training environment, and found that several of their training courses conducted both on- and off-site share a common course module. This course module, *Introduction to MOST*, is used in multiple training contexts, ranging from a course in overall performance management intended for organizations beginning the process of implementing performance standards programs, to an introduction to time study methodologies, and the BasicMOST technique. The training courses provided by Maynard have been presented solely by Maynard's Knowledge Center personnel, either at their customers' sites or their Training Center in Pittsburgh. Information regarding participant performance on exercises and assessments presented in these instructor-led courses are exclusively anecdotal. To date, no application of computer-based training by H.B. Maynard and Company as a delivery method to its world-wide customer base has been reported.

The *Introduction to MOST* course module considered here offers the opportunity to serve multiple objectives, including access to a diverse audience, the ability to reuse instructional objects (*e.g.*, lessons, pages, media) in other courses and contexts, and the requirement for brief interactive experiential activities that reinforce concepts presented within the course.

Virtual Laboratory Implementations

Multiple definitions for *virtual laboratory* are noted in the literature. We offer that a virtual laboratory should present a media-rich interactive environment of sufficient fidelity for conducting experimental activities commonly associated with some physical laboratory. In some cases, the virtual laboratory acts as a communication interface between its users and actual physical or software systems operating at a remote location. Examples include the networked robotics laboratories *Netrolab*[4] and *Second Best to Being There*.[5] A representative variation to these examples includes an interface to specialized modeling software running on remote servers to implement a virtual electromagnetic laboratory.[6]

The majority of virtual laboratories are implemented as software simulations of a component, device, or collection of devices relevant to the topic being studied, *e.g.*, an electronics workbench. An early example is described by Mosterman *et al.*[7] This virtual laboratory was designed and implemented at Vanderbilt University to facilitate the use of an existing introductory electrical engineering laboratory comprised of basic components and instruments. The authors found that a computer-based virtual laboratory of sufficient fidelity can improve student understanding, reduce requirements for physical laboratory resources, and increase student satisfaction with the learning experience. Many of the so-called virtual laboratories described in the literature are combined with some form of multimedia course delivery environment, *e.g.*, as a student-version of commercial software packaged on an accompanying CD-ROM or shared network disk resource, or embedded within the course delivery environment itself.[8,9]

Few virtual laboratory implementations intended specifically for manufacturing-related education, training, and research have been reported in the literature to date, no doubt owing to the complex system simulation and visualization issues involved. Notable here include work reported by researchers at the National Institute of Standards and Technology (NIST), which describes the development of a virtual manufacturing cell, intended primarily for research in system integration and control strategies.[10] This virtual manufacturing cell consists of software simulations of representative manufacturing equipment, processes, and systems. These simulations are implemented in commercial software applications running on diverse computer hardware and operating systems to support the various functionalities of the cell. Another approach to the modelling of virtual manufacturing system environments was considered by Onosato and Iwata.[11] They describe an object-oriented system architecture for their *VirtualWorks* factory modelling and simulation software running on a network of UNIX workstations. The authors suggest that when practical virtual manufacturing systems are realized, in addition to being used for the design and analysis of actual production systems, the integration of numerous lower level manufacturing and information systems technologies will make them useful educational and research tools.

World-Wide Web Applications in Technical Education and Training

Possible implementation strategies for an engineering courseware model using existing Internet and emerging WWW communication protocols were detailed by Bourne *et al.*[12] Technologies described by the authors include available text and graphical WWW browser client programs, the need for multimedia client helper applications, hypertext transfer protocol (HTTP) and file transfer protocol (FTP) servers, and the common gateway interface (CGI) of HTTP server systems.

While early WWW communication protocols were sufficient for the delivery of many forms of time-sensitive information, it has been argued that these protocols were inadequate for a distributed education and training environment.[13] The objections raised against the use of early WWW protocols for instructional delivery systems not withstanding, a great deal of interest in the use of current and *evolving* WWW protocols is being reported as their capabilities become better understood by educators. Multiple scalable WWW-based course management and presentation systems are being developed currently, addressing many of the limitations of static HTML documents. These systems typically provide instructors with tools for creating, organizing, and managing presentation and assessment material for multiple on-line courses through now-standard WWW interfaces. Recently, a great deal of activity has been aimed at extending instructional capabilities of World-Wide Web-based presentations through the use of small interactive programs. These small programs, known as *applets*, written in the Java programming language, are often embedded within standard HTML documents.

Objectives of the Virtual Laboratory

The primary objective of the research described here is the demonstration of a distributed virtual manufacturing laboratory (VML) that provides *experiential* (*i.e.*, active) learning support for Internet-delivered education and training programs in topics associated traditionally with manufacturing disciplines. We expect that these education and training programs could be offered by commercial developers of intellectual and software products to their customers, and colleges and universities to continuing education and matriculated students, both on- and off-campus (*i.e.*, via distance education modes).

The complete VML, as we envision it, is comprised of two coupled learning environments. The initial environment is comprised of a course delivery system capable of authoring, administration, and presentation of multimedia course materials via the global Internet. At present, this environment is implemented by a suite of proprietary Microsoft Windows-based authoring, administrative, and player client applications. Instructional content and its organization, in the form of descriptive courses, modules, lessons, and pages, are maintained in standard Structured Query Language (SQL) databases. The various clients communicate with the SQL database through the Open Database Connectivity (ODBC) interface. An experimental architecture-independent player, implemented in the Java programming language, forms the core of the course delivery system considered here.

The second major component of the VML provides an experiential learning environment to the course delivery system. Objectives for the integrated VML include:

1. The proposed VML consists of simulation models of typical physical environments to support the objectives of associated on-line courses. Common physical environments that

would be represented by the VML include assembly stations, manufacturing automation equipment, work cells, shop floors, virtual factories, *etc*.

2. The VML presents an appropriate user interface to provide visualization of sufficient fidelity and interaction of sufficient simplicity for it to be effective in a wide range of training and education applications (*i.e.*, across disciplines and educational levels).

3. The VML provides domain-specific views into common, integrated laboratory environments. For example, separate exercises for work measurement analysis, industrial robot programming, and computer numerical control machine tool programming present similar, though not identical, views of a common workcell simulation in which the view activates functionality needed only for that view.

4. The VML permits the specification of both guided and open-ended experiential investigations using predefined simulation models. Guided experiential investigations present a tutorial approach, with focused opportunities for experimentation at specific points. Open-ended investigations follow from a series of earlier guided laboratories (tutorials); these would provide participants the opportunity to test specific manufacturing automation program, for example.

5. The VML requires integration of reusable domain-specific simulators. For example, a work measurement analysis investigation may require the interpretation of one or more motion sequences, each comprised of multiple parameters. The simulator in this instance accepts parameter inputs appropriately and, when requested, interprets responses for subsequent analysis and diagnostics. In this case, the interface to the simulator could be implemented to resemble the interface of a commercial work measurement software product for use in a customer training program.

6. The VML maintains well-defined status information and results regarding progress through laboratory exercises. Time to complete tasks, task iterations, tasks started but not completed, and other assessment metrics are recorded by the VML.

7. The VML client is not limited to a single computer architecture *e.g.*, Microsoft Windows on Intel, Apple MacOS, various commercial and free UNIX environments, *etc.*, following the WWW paradigm. We argue that the use of architecture-independent client programs will allow a wider student population access to instructional resources provided by the VML, in that potential students are not required to use any *specific* computer hardware/operating system environment to make full use of the VML.

Macro-Architecture for a Virtual Manufacturing Laboratory

The availability of graphical World-Wide Web (WWW) browser programs (*e.g.*, Microsoft's Internet Explorer, Netscape's Communicator, Sun Microsystem's HotJava) simultaneously on a wide range of computer platforms has ushered in an era of unprecedented growth in access to digital information across the Internet. Working solely with static hypertext markup language (HTML) documents, these WWW browser programs are insufficient to provide a robust interactive learning environment. The current practice involves WWW server configurations that build appropriate HTML documents dynamically based on information from existing databases for presentation on generic WWW browsers. An alternate approach is to distribute the object-level processing to the client systems in an architecture-independent form. Graphical WWW browser programs that support embedded Java “virtual machines” provide the necessary platform independence for our research objectives. The Java programming environment enables the development of interactive applications without regard to the computer architecture upon which they run. We find that contemporary Java-enabled graphical WWW browsing programs, coupled with appropriate internetworking transport protocols for communication with database and HTTP servers, provide a rich systems environment for the implementation of distributed, interactive computer applications.

An existing CBT system forms the basis of an instructional delivery subsystem within the virtual manufacturing laboratory to distribute and present instructional content in a structured manner. The client side of this computer-based training subsystem is implemented as a Java applet that runs within a supported graphical WWW browser program. Figure 1 depicts an experimental release of the Java-based client running within Sun Microsystem’s HotJava WWW browser.

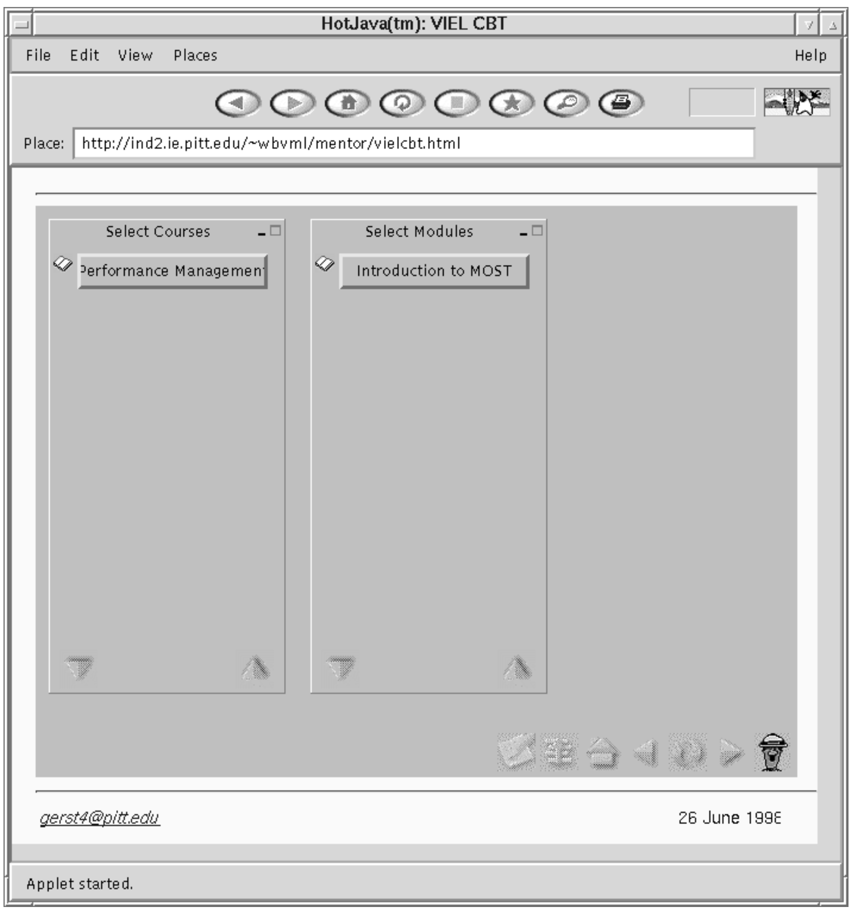

Figure 1 Client applet displaying available course and module selections

This client is expected to support the presentation of multiple media formats, including: ASCII and Unicode plain text formats; GIF and JPEG image formats; MPEG video format; AU audio format; *etc.* Figure 2 illustrates additional controls that guide navigation through the on-line course and media objects (text and static images) obtained from the Internet server.

Figure 2 Client applet displaying lesson selections and media content

Additional functionality of the Java client illustrated in Figures 1 and 2 should include, but is not limited to, prerequisites processing, progress status reporting, a collection of assessment question types with per-item record tracking, and hot-button processing to include opening new browser windows and calling Java methods.

In addition to providing necessary hypertext transfer protocol services, the server side of the VML provides database services to maintain course resources and student profiles (records). Course resources include data structures for course modules, lessons, and pages, interactive laboratories, navigation structures, and pointers to related media support files. Student profiles maintain detailed information on course, module, lesson, and laboratory usage, pre-requisite monitoring, and responses to quiz, test, examination, and survey items.

A simplified information architecture for the virtual manufacturing laboratory is illustrated in Figure 3.

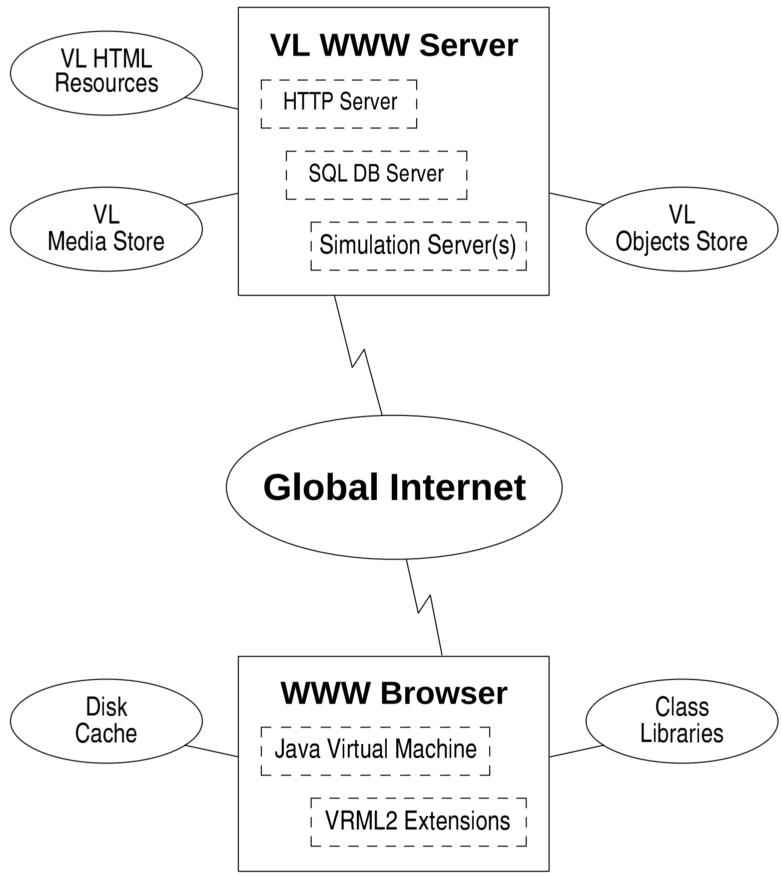

Figure 3 Information architecture for the Virtual Manufacturing Laboratory

We next consider the issues of three-dimensional visualization and interaction required in the VML. Tinker proposed the use of immersive virtual reality systems to facilitate the maintenance training function of concurrent engineering design teams.[16] Another early investigation into the use of immersive virtual reality was considered by Jones *et al.*[17] This research focused on the extension of two-dimensional graphical animations used in commercial discrete simulation software packages for manufacturing simulations with a three-dimensional immersive display environment. Recent research, however, suggests that the need for immersive virtual reality environments in educational applications may not be significant.[18] This finding argues for the development of an interactive, non-immersive, virtual manufacturing laboratory initially.

The Virtual Reality Modeling Language (VRML) was proposed as an architecture-neutral means of describing three-dimensional objects within the context of the World-Wide Web.[19] Level 2 of the VRML specification provides for functionalities required by our application, specifically, the programmable behavior of objects. While the availability of VRML2 interpreters and renderers is not currently as widespread as World-Wide Web browsing programs, we believe their current availability is sufficient to demonstrate the distributed VML described here.

Summary

This paper offered motivations for and potential benefits of a distributed virtual laboratory for manufacturing education. The distributed virtual laboratory we described here integrates a contemporary computer-based training delivery system with emerging open information systems, simulation, and visualization methods to form a distributed, architecture-independent, interactive experiential learning environment. We described a case-study in which the virtual laboratory is used to present a short-course for a Pittsburgh-area industrial engineering firm. We concluded by discussing an information system framework for our implementation of the virtual laboratory. The implementation and assessment of this virtual laboratory are the focus of on-going research at the University of Pittsburgh.

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