

Engineering A Virtual Machine Lab For Collaborative Engineering

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Abstract—When it comes to providing the learners with an enhanced conceptualization of the basics of engineering, laboratory exercises play a crucial role. This paper provides an overview of a simulated yet realistic software environment for the purpose of conceptual development of learners in the context of a technical laboratory. This virtual laboratory can be used as a pre-laboratory for learners to acquire some initial experience before their exposure to a real laboratory. This project entails the development of a virtual laboratory including several virtual experiments. Technical concepts are explained by means of text, 2D and 3D graphics as well as multimedia animation. An animated graphical users interface (GUI) provides the learners with the opportunity to acquire basic concepts and help them bridge their understanding from the virtual to the real laboratory. The laboratory system is accessible as a scalable web application on both the Internet, and popular mobile devices.

Keywords—*Virtual Power Laboratory, Generator/Motor, Animation, Web Application*

1. Introduction

Given the rapid proliferation of computer-based technologies into learning [1, 2], individuals are now able to access training programs and services anytime and anywhere as life-long learners [3, 4]. Benefiting from these trends, traditional laboratories are also no longer confined to the physical dimensions of space or time. Through a combination of recent Internet and web-based technologies these laboratories provide enhanced learning opportunities in the form of virtual laboratories. This paper presents the development of a virtual laboratory environment for electric machines.

A debate on which of the laboratory modes (hands-on versus digital) is better would be useless as each mode has its own perils and merits. The aim of this paper is not prove that virtual laboratories are necessarily “better” than hands-on laboratories as they could be designed for different purposes. Needless to say, in terms of effectiveness, a virtual laboratory should not be less effective than a hands-on laboratory if that is the only means available for the student to learn. Yet, within the field of engineering, the virtual laboratory can, and should, be designed to complement the physical laboratory and, if done correctly, should result in a better learning experience.

This paper provides an overview of a simulated yet realistic software environment for the purpose of conceptual development of learners within a technical laboratory. This virtual laboratory is designed to complement rather than substitute a hands-on laboratory, yet its design lends itself to appear as realistic enough to provide a satisfactory learning experience for participants who do not have access to a physical laboratory. This research study provides general information about the prototype of this virtual laboratory including its architecture, knowledge base and a set of related technical experiments. Adobe’s Captivate is suggested for the development of its software while Javascript can be utilized for coding its mathematical. In order to increase its degree of similarity to reality, a random number generator is recommended where some parameters can vary slightly around that of the nonlinear model in order to provide the learners with the opportunity to see different results every time they do an ‘experiment’.

This paper provides suggestions on the design and integration of the architecture required for the application of a virtual machine laboratory. Section 2 summarizes the computer aided learning systems with a focus on software environment while Section 3 discusses the architecture underpinning this virtual laboratory. Section 4 concludes with discussions on how to finalize the recommended prototype as a complete intelligent tutoring system for technical concepts.

2. Virtual Learning Environment

The introduction of computer-aided instruction (CAI) systems [5] goes back to as early as 1960's as a tool to support the learners outside the classroom environment. There were in general two types designs of these very first CAI programs: computerized versions of textbooks, or drill and practice screens [6] which provided immediate responses and/or feedback to the learners based on their responses to a particular problem. These computer-aided instruction systems were enhanced on an ongoing basis so that eventually their design was transformed into intelligent tutoring systems (ITS) [7, 8] so that by means of artificial intelligence explicit knowledge of the subject matter could be integrated into the system. Due to the rapid advancements in software design, real intelligent tutoring system have become a possibility by means of use of interactive development tools [9-11]. Within the existing body of literature, [12-14] there exists also a descriptive genre of research studies on the use intelligent agents, for a variety of tasks [15, 16].

There is an ongoing debate [17-19] about the comparative value of user experiences within a real laboratory and a virtual laboratory setting. Within a real world laboratory environment, as the learner needs to rely on a tutor he would not be able to access the tutor anytime and anywhere. On the other hand, although this issue of accessibility is alleviated by means of virtual laboratories due to providing an opportunity for self-paced, peer-collaborated learning [20-22], they may not be as effective as real laboratory environments when it comes to conveying practice experience with regard to electrical circuits [23-26], electronics [27, 28], control systems [29, 30], and various other courses. While hands-on laboratories emphasize design skills [31] simulations focus on conveying major learning concepts. To give a more specific example, learners using the virtual laboratory for chemical vapor deposition [32] thought that it was a very effective way of learning which may even be better than physical laboratories. Although a majority of learners using a virtual laboratory [33, 34] may prefer the hands-on laboratory, learners evaluated the virtual laboratory as an effective option for familiarizing themselves with the main dynamics of the hands-on laboratory, yet they did not find it suitable for acquiring some mathematical techniques and concepts.

The existing body of research about simulation environments for technical concepts can be mainly categorized as follows:

- a) a simulation environment based on Matlab/Simulink [35, 36],
- b) a conventional laboratory environment involving a computer data acquisition interface [37, 38], and
- c) a web-based virtual laboratory [39].

By means of [40] high level programming software, such as C++, Pascal, and the .NET framework, stand-alone simulation environments have also been designed. While these tools might offer tremendous opportunity for self-paced learning, learners may not be able to get any 'tutoring' support nor may they be able to acquire any operational experience in a realistic way. Some efforts have been made [37, 38, 41, 42] to make these laboratories more modern by putting modern data acquisition systems rather than traditional analog measuring tools into place. These setups usually consist of hardware-in-the-loop systems with a LabView interface for data acquisition as well as Matlab/Simulink environment for data processing.

3. Virtual Laboratory

A review of the existing literature suggests that the design of the intelligent virtual laboratory should take into the account the following objectives:

1) to transfer extracted classroom-based learning materials into the knowledgebase of the virtual laboratory,

2) to virtualize both experiments and equipment within the physical laboratory and

3) to design a web based software which learners can remotely access.

The design of the software environment for the virtual machine laboratory can be summarized as follows:

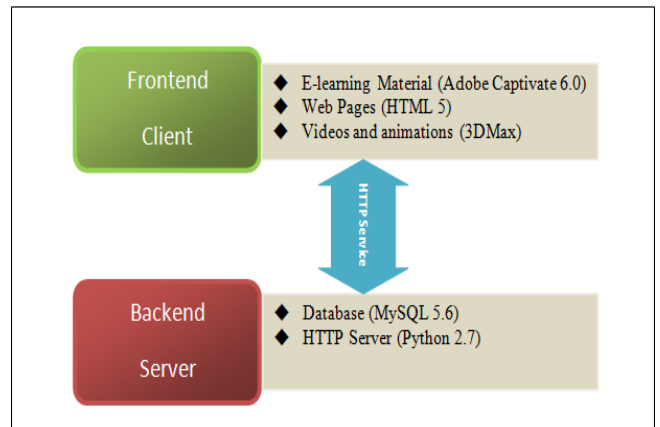


Figure 1. Technology for virtual machine laboratory

As shown in Figure 1, the implementation of the virtual machine laboratory is twofolds:

I) *Frontend Client*: The Frontend Client can be considered as a digital learning platform involving a variety of digital learning materials in the form of videos, voiceover, 3D animations, questions and quizzes.

II) *Backend Server*: The Backend Server can offer both secured *http* service as well as dynamic database management.

Security, stability and scalability are valid for both the Frontend Client and the Backend Server are designed to be secure, stable and scalable.

3.1 Frontend Client: eLearning Platform

An overview of the recommended architecture of the front-end digital platform has been displayed in Figure 2. Its interrelated modules are as follows:

- a) Multimedia User Interface
- b) Core Concept Knowledge base
- c) Experiment Knowledge Base
- d) Virtual Experiments
- e) Mathematical Tool Utility, and
- f) Intelligent Tutor [11][SEP]

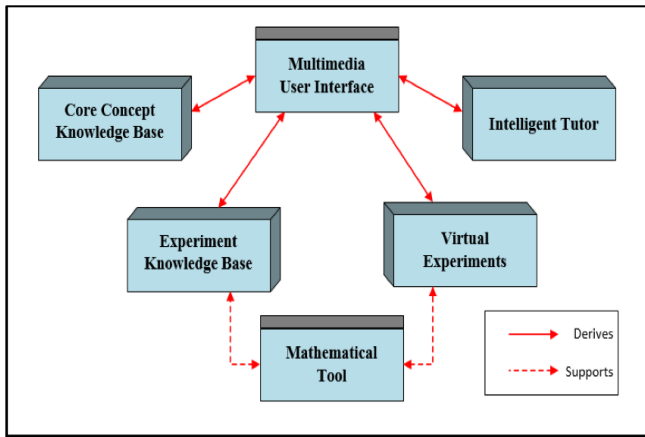


Figure 2. Architecture of the virtual machine laboratory

3.1.1 Multimedia User Interface

Upon the initial 'entry' of the learner into the virtual machine laboratory, the learner is guided via screens to select either conducting a review of basic operating principles, or undertaking an experiment. The *User Interface* allows the learner to interact with the software environment by using any human/computer interface device such as a mouse or a keyboard. The multimedia interface that has been designed by use of the Adobe's Captivate acts as a multimedia authoring system which entails a set of interactive modules. In case of the learner's selection for conducting an experiment, the learner is provided with a laboratory workbench and tools that are very much similar to those of a typical technical lab.

The graphical user interface (GUI) can be developed by using HTML and JavaScript programming languages so that they can be adapted to mobile devices, as well. Given the possibility of various different forms of the platform technology for virtual laboratories [43], a powerful Internet hosting module is crucial. This external interface aims to fulfill two purposes:

- to conduct data acquisition, signal conditioning and control in the virtual experiment setup, and
- to complete the necessary Internet computation and protocol procedures.

3.1.2 Core Concept Knowledge Base

The aim of the virtual laboratory is to enhance learners' knowledge on the main technical concepts about machines that should be both succinct and mathematically rigor. Therefore, by use of a multimedia model, a graphical illustration of the physical machine along with the related mathematical equations can be conveyed. All related formats such as video clips, three-dimensional (3D) animations, and voiceover guidance can illustrate the main concepts of the virtual machine.

Due to the interactive 3D animation integrated into the GUI, learners can understand in detail a set of sequential operations of the machine and visually

experience the machine as descriptive texts would provide technical details.

The multimedia core of the knowledgebase also acts as an interactive media that accompanies the learners through a step-by-step learning process. By means of a multimedia module complicated knowledge can be simplified into intuitive expressions. To give a specific example, voiceovers can be utilized to reinforce students' learning experience.

Having gathered information from the traditional teaching resources, the main module of the concept knowledge base could be classified into the following three types:

1) The **descriptive knowledge** could be conveyed in the form of the multimedia core using animations, images as well as voiceovers as it would mostly entail indicative propositions or declarative sentences to explain the 'tedious' or complex concepts. In this way, learners can graphically associate these concepts with the realistic mechanism underpinning the concepts and therefore getting involved in an interactive process.

2) The **interpretive knowledge** refers to the knowledge of how to conduct certain tasks in the best way. So, within the setting of a laboratory environment, this would refer to instructional guides based on conventional laboratory manuals. Given the nature of this type of knowledge and the related "how-to" or "why" questions, this knowledge may not easily be interpreted, yet by coupling all related knowledge within database an *intelligent tutor* module, this knowledge can be captured within the system.

3) The **mathematical knowledge** base consists of the mathematical descriptions with regard to the technical operations of a machine. Therefore, this type of knowledge can be conveyed via means of text, graphics, and voiceover.

All of these knowledge categories are subject to query by other modules of the software. Whenever a need arises, the knowledge base may be revised for the purposes of for correctness and usability based on the evaluation process.

3.1.3 Experiment Knowledge Base

Various prototype experiments can be conducted to facilitate the learners' understanding on the principle of machine operation. These experiments can be designed based on the ones conducted commonly in real laboratory environments.

One of the major differences between the experiment knowledge base and the core concept knowledge base is the experiment knowledge base's requirement for a connection between the Frontend Client and Backend Server with regard to the accessibility from the majority of mobile devices. By use of the mathematical engine MatLab, the mathematical contents of the experiment knowledge base can be coded and tested on a standalone

platform. As the virtual laboratory is developed as a scalable web application, the Matlab code needs to be replaced by the related JavaScript platform.

3.1.4 Virtual Experiments

In the virtual experiments module, the learner is provided with the opportunity to gain an overview of technical components by connecting the different components or a series machine as appropriate. The learner is also provided with the option reviewing the technical configuration via means of the knowledgebase of various machines. Once the learner has a satisfactory understanding of the technical configuration for the experiment, the experimental process can be started by turning on the power button.

Once a virtual experiment is started on a machine, the *Experiment Knowledge Base* module initiates the mathematical model in the background by sending real-time data streams for being displayed on virtual instruments. In this way, learners can have a realistic understanding of machine mechanism through the virtual experiment.

Moreover, the virtual experiment provides the learner also with the opportunity to play 'what if' scenarios on the operation of a machine. To give a specific example, one may ask what happens to a machine if the applied voltage reduces by 50%, or if the load increases by 50%. These types of experiments cannot be safely performed in a real machinery laboratory. The virtual laboratory will provide the learner with the unique opportunity to undertake these experiments without incurring any real physical damage of the machine or measuring equipment. Figure 3 provides a screenshot of the sample measurement data from a similar experiment. Once the experiment is concluded, results can be plotted on the computer screen.

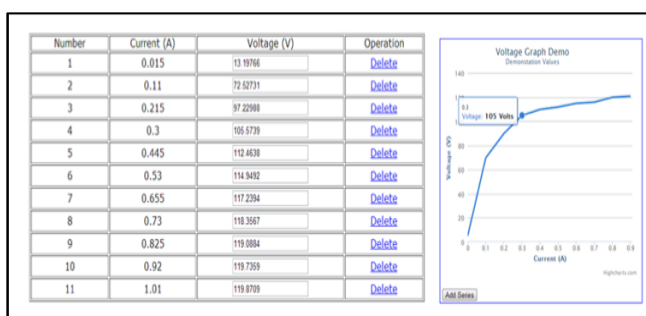


Figure 3. Sample user record and plot of results

3.1.5 Mathematical Tool Utility

The Mathematical Tool Utility can be conceptualized as a conventional mathematical application coded in Java that entails those mathematical operations required in the virtual laboratory.

3.1.6 Intelligent Tutor

The intelligent tutor module can act as a virtual laboratory assistant that "watches" what the student is

doing and learns from the student's actions, what the student knows, does not know or knows incorrectly. The tutor software can be an AI module [24] based on rules and procedures that relate the student's knowledge to that needed to perform the experiment successfully. The intelligent assistant can maintain a dynamic model of the student's interactions during the experimentation. The intelligent assistant's suggestions will be based on its evaluation of the student's knowledge along with what knowledge is required at that specific point in the laboratory. In case the student may need additional background material on an experiment, the intelligent assistant can prompt the student to find it from the Experiment knowledgebase. The intelligent tutor will also maintain a log of student's progress in the laboratory material, and will guide the student accordingly.

3.2 Backend Server

The Backend Server can be implemented as a secured Python HTTP service for wired or wireless networks. The whole architecture enables the reliable real time data exchange channels among the servers, web browsers and various databases. The servers collect and transfer real-time data from dynamic databases, and distribute these data to end users' web browsers. A sample overview of the suggested basic architecture of the virtual laboratory is shown in Figure 4. The whole Backend Server system has a three-tier structure offering various web based services:

- 1) User Interface^[25]
- 2) Transitional Server
- 3) Data Server

3.2.1 User Interface

The user interface is the "bridge" connecting the Frontend Client and Backend Server. It offers different services to different users for various user-to-machine or machine-to-machine communication.

1) *User-to-machine services*: The log-in process of the server can offer the following suggested privileges to the users based on their classification:

a) *Students*: Student users can access all resources in the multimedia data server including all the learning materials, videos, experiments and so on, however they are not allowed to access other user's account information.

b) *Instructors*: Instructor users have full access to all learning materials and students records, such as grades, experimental data collected by students, etc. Instructors also have permission to change any learning material however they may not change server database management codes and protocols.

c) *Visitors*: The visitor users have the limited authority to access to the system for learning material without creating a user's profile.

d) *Administrative user(s)*: An administrative user is responsible for maintaining the server for its security and efficient interface with the Internet.

These different types of users can access the system through a variety of human-machine interfaces, such as keyboard/mouse, touch screens as input interfaces and monitors, projectors as output interfaces and so on.

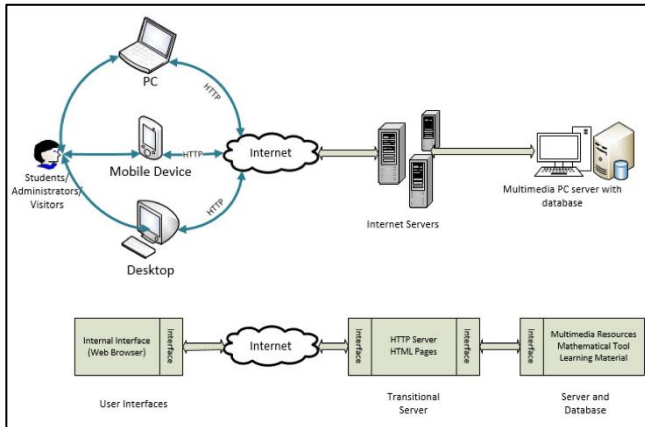


Figure 4. Sample Internet interface

2) *Machine-to-machine services*: The suggested virtual laboratory is expected to be a web based application that can be accessed from commonly used intelligent devices, such as personal computers, mobile devices, laptops, wearable intelligent devices and so on. Different services are performed depending on the device used. For example, mobile devices can send requests to the transitional server for low resolution videos to reduce data flow. In all the scenarios, the communication procedure is performed through HTTP protocol using HTML coding. As a common static web programming language, HTML is the best candidate to support a majority of web services for different devices. Furthermore, PHP and Javascript scripts are applied as an auxiliary tool to support database management and dynamic animation deployment accordingly.

3.2.2 Transitional Server

The suggested transitional server in this architecture refers to the integrated Python web server with several CGIs (Common Gateway Interface) deployed on HTTPS services. Communication through this server is filtered by a firewall. Thus the transitional server can be implemented as a secured communication center. In general, Python-PHP CGI can be deployed to send PHP requests through HTTP protocol so that the database can be accessed dynamically; and Python-HTML CGI is implemented to offer HTML service remotely. Both of these CGIs can translate all the communication procedures into web signals and display them accordingly at the user end web browsers.

3.2.3 Data Server

The suggested data server acts as the main Internet host machine (multimedia PC with internal interface) to accommodate all procedural steps and to provide immediate responses towards commands activated by the end-user through the particular web-pages designed for this specific application. The Internet host machine is capable of providing efficient secured data streaming and of hiding the underlying scripting methods from any external intrusions. The data server hosts various databases, such as Learning Material Database, Multimedia Resource database and User Information database, etc. These databases are managed by the data server which responds to user requests sent from different services. Also the different privileges are assigned and managed by this data server when different users are registered.

4. Conclusions

This paper presented the architecture of the suggested virtual laboratory, and as a proof of concept, presented a prototype system for a set of technical experiments. Multimedia is suggested to be incorporated to provide convenient visual and aural guidance for students to understand the concepts better. The virtual laboratory ideally includes a knowledge base and experiments for different machines commonly found at typical physical laboratories. Furthermore, the virtual laboratory can be accessed through the Internet.

Further research is required to embed the intelligent tutoring system so that the 'virtual *tutor*' can assess the student's progress and guide the student with prerequisite material on the subject matter. Once fully developed, the virtual laboratory can include the knowledge bases and experiments commonly found at typical physical laboratories.

This laboratory is an attempt to bring the best of both worlds in the learning environment: the richness of domain knowledge and the expert support of an intelligent agent in a realistic simulation of physical laboratory environment. It should not be automatically assumed that a virtual laboratory is a substitute for a physical laboratory, rather it can be used to complement students' learning as pre-laboratory experience or as an alternative at institutions where hands-on laboratory instruction is not possible because of safety issues, expense, and lack of qualified teaching assistants.

In this age of fast change and rapid technological proliferation, we need young people to get more interested and motivated in engineering to secure our future. Young people have experienced computer games and simulations throughout their lives, which are becoming important tools in delivering educational materials. The virtual laboratory allows students to be exposed to engineering by a path that is not only inviting but one with which they are most familiar.

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