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A Realistic Intelligent Multimedia Virtual Laboratory for Power Engineering

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A REALISTIC INTELLIGENT MULTIMEDIA VIRTUAL LABORATORY FOR POWER ENGINEERING

Abstract

Laboratory works and exercises play an important role in learning and increasing students' understanding of basic concepts in engineering. Although a laboratory practicum is often considered a key component of engineering education, a hands-on approach is often ignored for courses involving electrical machines for various reasons, such as safety, expense, and lack of qualified teaching assistants. In this paper, we present the on-going development of a realistic software environment which simulates an electrical machines laboratory. This virtual laboratory[1] can be used by students as a safe test bed or a pre-laboratory for gaining experience before they encounter machines in a real laboratory. As a proof of concept, this project develops a virtual laboratory for DC machines with several virtual experiments for motors and generators. Machine concepts are summarized using text, 2D and 3D graphics as well as multimedia animation. An animated graphical users interface (GUI) plays an important role in this system as it enables students to review and retain basic concepts and builds a bridge from the virtual to the real laboratory. The laboratory system can be accessed through the Internet, and as a scalable web application of popular mobile devices.

Key Words: Virtual Power Laboratory, Generator/Motor, Animation, Web Application

1. Introduction

A laboratory practicum is considered a key component of engineering education; however a hands-on approach is often ignored for courses involving electrical machines because of safety issues, expense, and lack of qualified teaching assistants. Traditionally, machines used in power laboratories run at standard line voltage which makes safety an issue requiring that these laboratories be closely supervised. The IEEE Power Engineering Education Committee (PEEC) Task Force on Education Resources [1] recently surveyed universities in the United States to determine the state of power education. Within the 118 schools that participated in the survey, 202 laboratory courses (or less than 2 per program) were offered that were related to power systems or electrical machines. More than 26 out of 118 schools surveyed in [1] offering power-related courses had no laboratory support.

Over the last decades, internet and computer based technologies have developed exponentially [2, 3], which has made education a lifelong activity [4]. As a result, educational facilities could be expanded to provide programs and services anywhere and at any time. To solve the limitations of traditional machine laboratories, an overall web-based laboratory environment offers a possible alternative to providing training and learning materials. Considering the advantages of combining current internet and web-based technologies with educational purposes, the paper presents the development of a virtual laboratory environment for electric machines.

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Whether or not virtual laboratories are as good as or will replace hands-on laboratory is debatable, and in fact, is a basically useless debate. In our opinions, there is no reason why virtual laboratories need to be "better" than hands-on laboratories if they are designed for different purposes. Clearly, a virtual laboratory has to be as effective as a hands-on laboratory if that is all the student has with which to learn. But in most instances, especially within engineering, the virtual laboratory can, and should, be designed to complement the physical laboratory and, if done correctly, should result in a better educational experience.

This paper presents the development of a simulated but realistic software environment for an electrical machine laboratory. It is designed to complement a hands-on laboratory, but it is expected to be realistic enough to provide a satisfactory stand-alone experience for students who do not have access to a physical laboratory. As a proof of concept, we present here a prototype virtual laboratory for DC machines and discuss its architecture, its knowledge base and a set of experiments for DC motors and generators. The software system is developed using Adobe's Captivate, and the mathematical engine is coded in JavaScript. For a realistic simulation, we use the nonlinear magnetization characteristic of the machine rather than the linear model commonly found in textbooks. Also, a random number generator has been used to vary the induced voltage of the machine slightly around that of the nonlinear model so that students will see different results every time they do an '*experiment*'.

This paper is a 'work-in-progress' report on the development and integration of the architecture necessary for the implementation of a virtual electric machine laboratory. Section 2 summarizes the computer aided learning systems with special emphasis on software environment for electrical machines. The architecture of the virtual laboratory is presented in Section 3. The paper is concluded in Section 4 with discussions on plans for extending the developed prototype to a complete intelligent tutoring system for electrical machines.

2. Virtual Education Environment

Computer-aided instruction (CAI) systems [5] were introduced as early as 1960's as a means of assisting students outside the classroom. The first CAI programs were either computerized versions of textbooks, or drill and practice monitors [6] that presented a student with problems and compared the student's responses to the pre-scored answers, and if necessary, provided the student with canned remedial responses. Improvements were continuously made until computer-aided instruction systems evolved into intelligent tutoring systems (ITS) [7, 8] when artificial intelligence was used to embed explicit knowledge of the subject matter. Recent advancements in software along with interactive multimedia development tools have created a software environment that makes real intelligent tutoring system a possibility [9-11]. Recently references [12-14] described some intelligent agents, and systems with intelligence have been proposed for a multitude of tasks [15, 16].

There is also a debate [17-19] over the value of a virtual laboratory as well as the comparative user experiences between a real laboratory and a virtual laboratory. While a real world laboratory gives the student an opportunity to gain some practical experience, the student must rely on self-learning of concepts or on a human tutor who may not be available at a time when the student needs the tutor most. Conversely, virtual laboratories provide better accessibility and learning in a self-paced, peer-collaborated environment [20-22] leading to the development of various web based interactive laboratory systems, such as for electrical circuits [23-26], electronics [27, 28], control systems [29, 30], and various other courses. Reference [31] finds that hands-on laboratories emphasize design skills while simulations emphasize learning concepts. Students using the virtual laboratory for chemical vapor deposition [32] felt that it "….was the most effective learning medium used in the course, even more so than physical laboratories." Other assessments have mixed results. Students using a virtual laboratory [33] for a biology course prefer the hands-on laboratory, but a clear majority (60.8%) perceives the virtual laboratory as effective. Reference [34] found that students perceived a virtual chemistry laboratory as an effective option for familiarizing themselves with the workings of the hands-on laboratory, but did not find it adequate for learning mathematical techniques and concepts for chemistry.

Prior research on simulation environments for electrical machines can be broadly classified into three categories: a) a Matlab/Simulink based simulation environment [35, 36], b) a traditional machinery laboratory with a computer data acquisition interface [37, 38], and c) a web based virtual machine laboratory [39]. Standalone simulation environments have also been developed [40] using high level programming software, such as C++, Pascal, and the .NET framework. The EMSP (Electric Machine Simulation Program) [41] models electric machines using ANSI/IEEE/NEMA standards and manufacturer supplied parameters. While these simulation environments are excellent tools for self-learning of machine concepts, students do not receive any 'tutoring' support nor do they gain any experience on operation of a machine in a realistic application. Attempts have been made [37, 38, 42] to modernize machine laboratories with replacing traditional analog measuring instruments by modern data acquisition systems. These setups are essentially hardwire-in-the-loop systems with LabView providing the interface for data acquisition, and a Matlab/Simulink environment for data processing.

3. Virtual Machine Laboratory

The design of the intelligent multimedia virtual machines laboratory focuses on three main objectives: 1) to extract learning materials from traditional machine classes and compile them in the knowledgebase of the virtual laboratory, 2) to virtualize laboratory experiments and physical laboratory equipment and 3) to design and manage web based software that can offer services remotely accessed by students. The following paragraphs provide a description of the development of the software environment of the virtual machine laboratory.

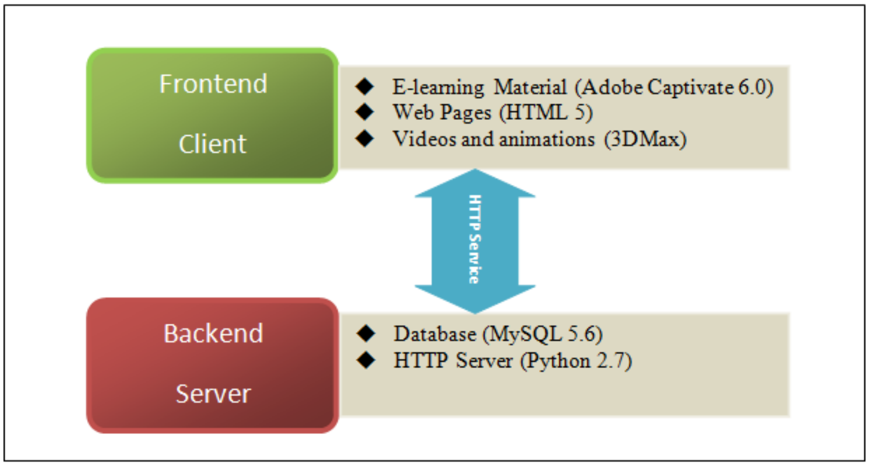


Figure 1. Technology for Virtual Machine Laboratory

As shown in Figure 1, the virtual machine laboratory is implemented in two parts: a Frontend Client and a Backend Server. The Frontend Client is an e-learning platform consisting of e-learning materials, videos, voiceover, 3D animations, questions and quizzes. The Backend Server has the ability to offer secured *http* service as well as dynamic database management. Both the Frontend Client and the Backend Server are designed to be secure, stable and scalable. This laboratory system can be accessed through the Internet for a majority of current popular mobile devices.

3.1 Frontend Client: eLearning Platform

Figure 2 shows the architecture of the front-end eLearning platform, which is organized as several interconnected modules:

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

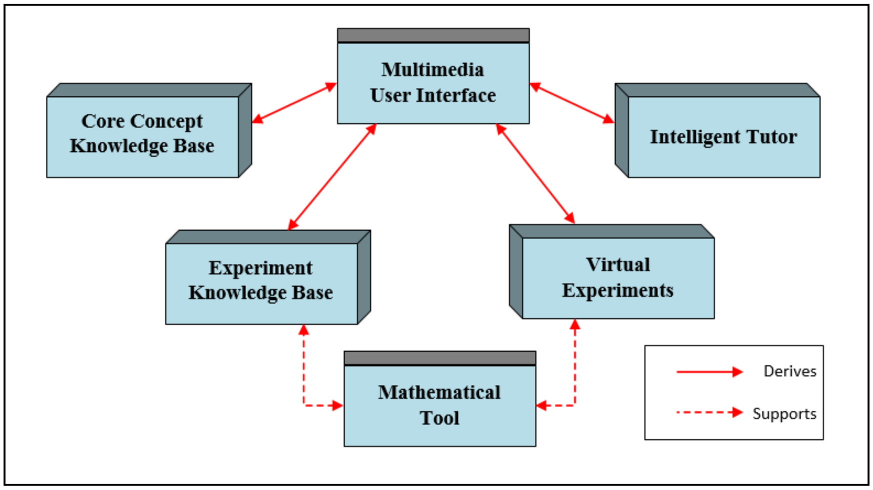


Figure 2 Architecture of the Virtual Machine Laboratory

3.1.1 Multimedia User Interface

As the student '*enters*' the virtual laboratory, the initial screen guides the students to choose one of the options, such as review basic operating principles, review the construction of the machine, or do an experiment. The student interacts with the software environment through the *User Interface* using a mouse, keyboard or any human/computer interface device. The multimedia interface is a set of interactive modules, developed using the Adobe's Captivate, a commercial multimedia authoring system. If the student chooses to do an experiment, a laboratory workbench is presented to the student with machines and instruments similar to those found in a typical physical machines lab.

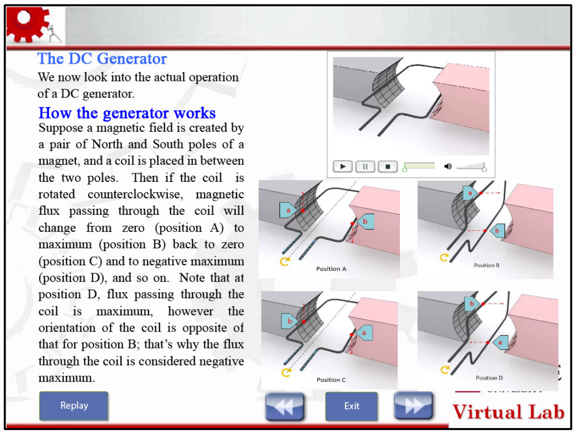
The user interface, implemented as a GUI interface, is implemented using HTML and JavaScript programming languages, which make the interface adaptable to popular mobile devices. Because the platform technology for web based laboratories could take different forms [43], the common feature among all platforms is a powerful Internet hosting module. This external interface has two purposes: the first is to perform data acquisition, signal conditioning and control in the virtual experiment setup, and the second is to do the necessary Internet computation and protocol procedures.

3.1.2 Core Concept Knowledge Base

This virtual laboratory is expected to acquaint students with the fundamental concepts of electrical machines, in particular the DC generator and DC motor. The core concepts must be conveyed in succinct paragraphs yet with sufficient details and mathematical rigor. Thus, it is necessary to create a multimedia model that can graphically illustrate the properties of the physical machine as well as describe its properties using appropriate mathematical equations. In our system, the multimedia core consists of video clips, three dimensional (3D) animations, and voiceover guidance. This multimedia core plays an important role in the virtual laboratory system as it illustrates the basic concepts using graphics and texts.

The GUI shown in Figures 3 and 4 implement a fully operational multimedia core together with the description texts. This allows the student to visually experience and understand the physical machines. The interactive 3D animation embedded in Figure 3 performs a complete set of sequential operations of a DC generator to describe the generation of voltage as a coil rotates in a magnetic field.

The multimedia knowledgebase core is not only a collection of critical concepts of the machine but also is an interactive media that takes the students through a step-by-step learning process. The aim of this multimedia module is to offer a simple and straightforward learning tool that can simplify the complex fundamental knowledge into intuitive expressions. For example, voiceovers are also embedded in *core concept knowledge base* and other modules to reinforce students' learning experience.



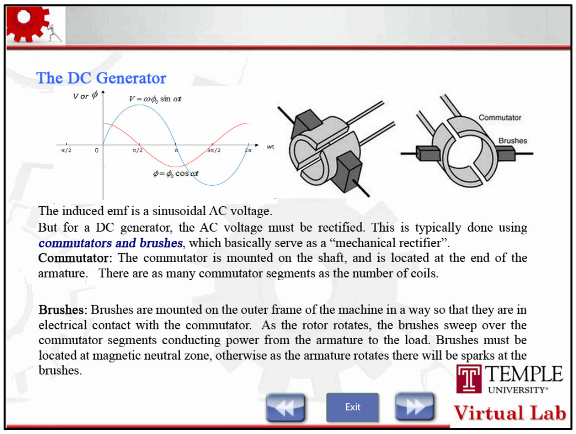
The DC Generator

We now look into the actual operation of a DC generator.

How the generator works

Suppose a magnetic field is created by a pair of North and South poles of a magnet, and a coil is placed in between the two poles. Then if the coil is rotated counterclockwise, magnetic flux passing through the coil will change from zero (position A) to maximum (position B) back to zero (position C) and to negative maximum (position D), and so on. Note that at position D, flux passing through the coil is maximum, however the orientation of the coil is opposite of that for position B; that's why the flux through the coil is considered negative maximum.

Figure 3. Multimedia Core Animation



The DC Generator

The induced emf is a sinusoidal AC voltage.

But for a DC generator, the AC voltage must be rectified. This is typically done using ***commutators and brushes***, which basically serve as a "mechanical rectifier".

Commutator: The commutator is mounted on the shaft, and is located at the end of the armature. There are as many commutator segments as the number of coils.

Brushes: Brushes are mounted on the outer frame of the machine in a way so that they are in electrical contact with the commutator. As the rotor rotates, the brushes sweep over the commutator segments conducting power from the armature to the load. Brushes must be located at magnetic neutral zone, otherwise as the armature rotates there will be sparks at the brushes.

Figure 4. Multimedia Core

The core concept knowledge base module is a collection of the fundamental information extracted from traditional teaching materials. It is categorized into three different types:

1) Descriptive knowledge
2) Interpretive knowledge
3) Mathematical knowledge

The ***descriptive knowledge*** is extracted from standard text books on electrical machines used at universities. It is naturally expressed in declarative sentences or indicative propositions to elaborate the complex conception in a simple way. For example, Figure 3 shows change of flux through a coil rotating in a magnetic field. Figure 4 shows the description of brushes and commutators in a realistic DC generator. The knowledge is transcribed in the multimedia core using animations, images as well as voiceovers. In this way, "tedious" concepts are expressed by an interactive process, which can help students to graphically associate the knowledge with the realistic mechanism behind the concepts.

Interpretive knowledge is defined as the knowledge of how, and especially how best, to perform certain tasks. In this laboratory, this type of knowledge includes all instructional guides for experiments extracted from typical machine laboratory manuals. Due to the content of this type of knowledge, it is difficult to provide a straightforward discussion to help the students interpret the knowledge behind the lab instructions, for example, some of the "how-to" or "why" questions may not have a direct answer. In this project, the authors are compiling all possible interpretive knowledge together in the database, which will be eventually coupled with the *intelligent tutor* module.

The ***mathematical knowledge*** base provides the mathematical descriptions of the operation of a DC machine in both transient and steady state modes. For example, the speed of a shunt motor can be described using circuit equations based Kirchhoff's current and voltage laws. These equations are precisely presented and are embedded using text, graphics, and voiceover as necessary.

All of these knowledge sub-bases are constituents of the main knowledge base of this project. They are queried by other modules of the software. The knowledgebase may be updated during the evaluation process for correctness and usability.

3.1.3 Experiment Knowledge Base

A set of laboratory experiments on DC Machines, similar to those commonly used in real laboratory courses, has been developed in the virtual laboratory, such as

1) Magnetization characteristics of a separately excited machine
2) Voltage buildup of a shunt generator
3) Loading of a shunt generator
4) Series generator load characteristics
5) Compound generator load characteristics
6) Starting of a shunt motor
7) Speed control of a shunt motor
8) Torque speed characteristics of a shunt motor
9) Torque speed characteristics of a series motor

The prototype experiments help students to understand the principle of machine operation, its unique connection to an electrical circuit, and allow them to measure various quantities, such as current, power, voltage etc. The virtual machines have a default rating in terms of operating voltage, current, and power, which however can be changed by the user if necessary.

For each experiment, the machine circuit model is expressed using standard equations (omitted here for brevity) based on Kirchhoff's voltage and current laws. For armature induced emf, we use the Langevin function (1), which is a more realistic representation of magnetic saturation than the linear approximation commonly found in textbooks. In addition, Newton's laws have been used to describe the speed profile of the machine state as a function of time.

$$L(x) = A(\coth(\frac{x}{a}) - \frac{a}{x}), \tag{1}$$

where coth is a hyperbolic cotangent function, and A and a are appropriate constants. Using the Langevin function, induced emf in the armature is expressed as

$$E = L(I_F) + r \tag{2}$$

where r is a small random number, and I_F is the field current. Thus every time a student performs an *experiment* using the virtual laboratory, the random number r will be different so that the corresponding induced emf will be slightly different even if the field current is same. This makes the *experimental* results of the virtual laboratory not exactly repeatable as is commonly observed in a real laboratory.

The experiment knowledge base is designed similarly as the core concept knowledge base. The main difference is that the experiment knowledge base requires a connection between the Frontend Client and Backend Server to facilitate access of the contents from various mobile devices. Initially the mathematical contents of the experiment knowledge base were coded and tested using the Matlab mathematical engine on a separate standalone platform. Since the virtual laboratory must run as a scalable web application that can be accessed by a majority of the current mobile devices, the Matlab code had to be replaced by the corresponding JavaScript platform.

3.1.4 Virtual Experiments

In the virtual experiments module, the student is presented with a circuit template (Figure 5) with the basic circuit components required for a typical experiment, such as the machine armature, field windings, open jumper positions for ammeters and voltmeters, rheostats as well as a load or power supply. The student then connects the various components as a shunt machine or a series machine as appropriate. If needed, the student can go back and review the circuit configuration or basic concepts using the knowledgebase of various machines. Once the student is satisfied that the circuit configuration for the experiment is correct, the student initiates the experiment by turning on the power button.

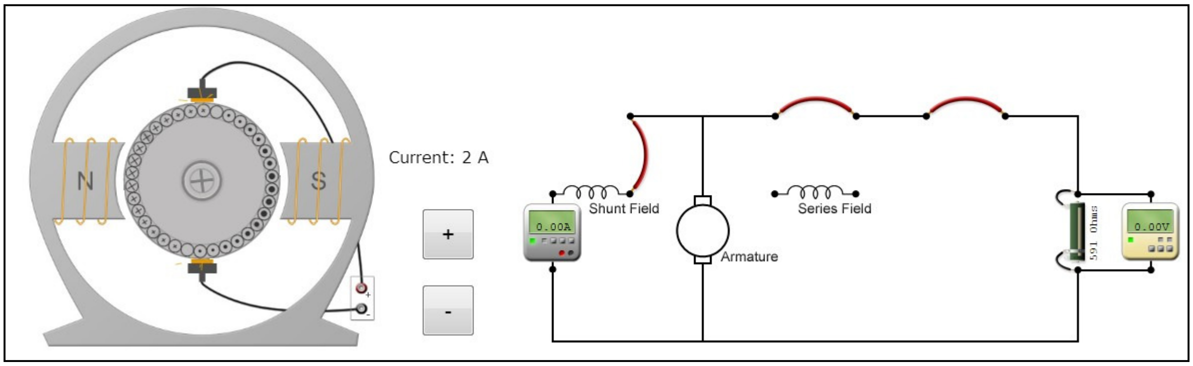
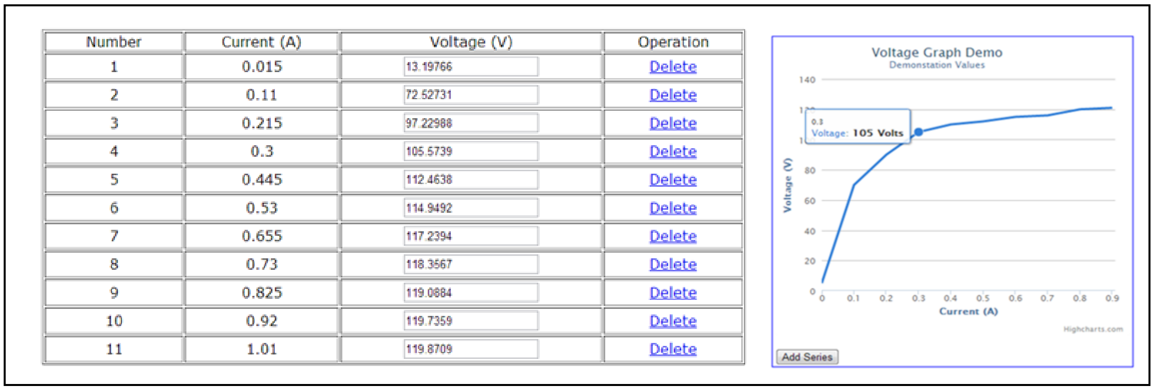


Figure 5. Machine Circuit Diagram Template

For the virtual laboratory, once a machine is started, the *Experiment Knowledge Base* module runs the mathematical model of the machine in the background and sends a data stream of various circuit quantities to be displayed on virtual instruments. This data stream comes in real time and creates a feeling that an actual machine is running in real time. Sound effects have been added for motor experiments to produce a more realistic operating condition, such as a change in sound emitted by the rotor when speed changes. In order to better virtualize the equipment, the animated machine simulates sparks at the brushes as the turbine rotates. Students can clearly picture the realistic machine mechanism through this virtual experiment.

One of the important aspects of this virtual experiment is to play *'what if'* scenarios on the operation of a machine. For example, one may ask what happens to a DC shunt motor 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 a unique opportunity to the students to conduct these experiments without incurring any real physical damage of the machine or measuring equipment. Figure 6 gives a screenshot of the measurement data from a typical experiment. Although it is possible to automatically populate the table with experimental data, the authors decided to allow the user to manually record the experimental data as is done in a real physical laboratory. Once the experiment is concluded, results can be plotted on the computer screen.



Number	Current (A)	Voltage (V)	Operation
1	0.015	13.19766	Delete
2	0.11	72.52731	Delete
3	0.215	97.22988	Delete
4	0.3	105.5739	Delete
5	0.445	112.4638	Delete
6	0.53	114.9492	Delete
7	0.655	117.2394	Delete
8	0.73	118.3567	Delete
9	0.825	119.0884	Delete
10	0.92	119.7359	Delete
11	1.01	119.8709	Delete

Figure 6. User record and plot of results

3.1.5 Mathematical Tool Utility

The Mathematical Tool Utility is a typical mathematical utility coded in Java containing those mathematical operations required in the virtual laboratory.

3.1.6 Intelligent Tutor

The intelligent tutor module is a work-in-progress. Once fully developed, the intelligent tutor is expected to 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 will 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 will 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 needs additional background material on an experiment, the intelligent assistant will 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 is 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. The basic architecture of the virtual laboratory is shown in Figure 7. The whole Backend Server system has a three-tier structure offering various web based services:

1) User Interface
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 offers different privileges to the users based on their classification: a) students, b) instructors, c) visitors, and d) administrative user(s). 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. 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. The visitor users have the limited authority to access to the system for learning material without creating a user's profile. 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.

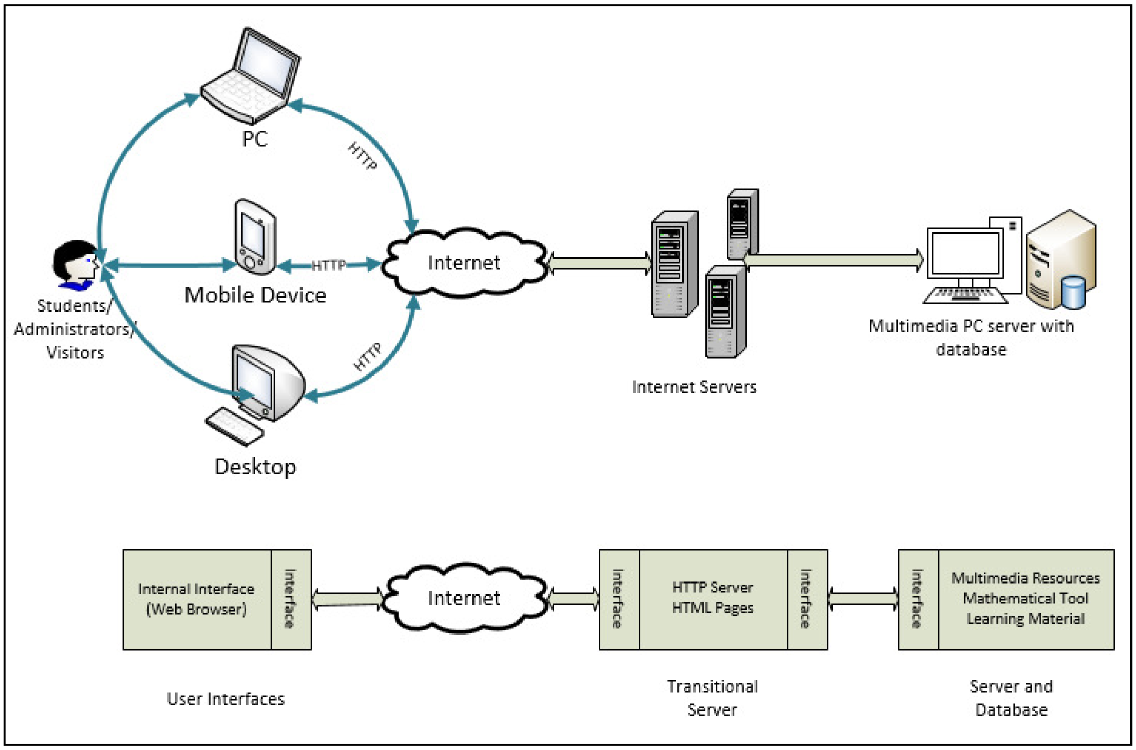


Figure 7. Internet Interface

2) Machine-to-machine services: This 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 transitional server is 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 is implemented as a secured communication center. In general, Python-PHP CGI is 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 translate all the communication procedures into web signals and display them accordingly at the user end web browsers.

3.2.3 Data Server

The data server is 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

We presented the architecture of the virtual laboratory, and as a proof of concept, present a prototype system for a set of experiments on DC machines. The DC machine has been simulated using standard circuit equations, a nonlinear magnetization characteristic, and Newton's law for dynamics. Multimedia is incorporated to provide convenient visual and aural guidance for students to understand the concepts better. The virtual laboratory includes a knowledge base and experiments for different machines commonly found at typical physical laboratories for electrical machines. Furthermore, the virtual laboratory can be accessed through the Internet.

Further research is in progress 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 will include the knowledgebases and experiments for different machines commonly found at typical physical laboratories for electrical machines.

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. We do not feel 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.

This nation needs young people to become interested in power 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 power engineering by a path that is not only inviting but one with which they are most familiar.

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