Web Services Remote Educational Laboratory

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Abstract — *Our Internet enabled laboratory, Lab-on-Web, is dedicated to remote, educational experimentation on electronic devices and circuits. It has evolved over several years and different system solutions have been tested. Here, we report on the recent adaptation of the Web Services standards to Lab-on-Web, implemented by means of the .NET framework by Microsoft. This framework allows for a strong integration between backbone programs, web applications, and services such as modern learning management systems. Other important properties intrinsic to Web Services and .NET are, for example, system stability, platform independence, excess control, rapid development, and interoperability with other applications.*

Index Terms — *Remote laboratory, Web Services, Semiconductor, Instrumentation*

INTRODUCTION

Laboratory experiments are a vital part of engineering and science education. The concept of making educational laboratory experiments available to students over the Internet has been around for many years, and several groups have realized proof-of-principle versions, some of which have even been adopted in university courses [1]. Obvious benefits can be derived in terms of sharing expensive facilities between institutions and in terms of flexibility for the students, allowing expensive hardware resources to be utilized far more efficiently than with traditional hands-on laboratories. Although the virtues of traditional laboratory work within many disciplines of engineering and science are unquestionable, there is a trend in the operation of advanced electronics instruments away from turning knobs to using menu oriented interfaces where the interaction takes place via display screens. From there, the leap to remote operation via the Internet using a computer interface at the client side is not so big.

The idea of sharing laboratory resources between institutions has prompted collaborative efforts such as eMerge, a project sponsored by EU's Socrates/Minerva program, where the integration of partner laboratory facilities into a coordinated network is explored [2]. Within this project, the technical and educational potentials of this new technology are also important issues to be investigated.

In many respects, the Internet laboratory technology is still in its infancy. The approach so far has been to use basic scripting or backend programs to support access to instruments and experiments. Common experiments are then visualized through applets or static HTML controls to provide the clients with the necessary functionality to perform their experimental tasks. However, based on our experiences so far, we now see great benefits by rigid adherence to accepted standards for exchange of middleware services via the Internet, such as the Web Services open standards. Presently, Lab-on-Web utilizes Web Services interfaces within Microsoft's .NET framework hosted by a Windows 2003 server. The basic functionality of Lab-on-Web is illustrated in Figure 1.

The above features open the way for Internet laboratories to become part of an even wider learning context, for example, through integration and interoperability with modern Learning Management Systems (LMS). An LMS is a powerful tool for enhancing learning processes and managing course resources. Such tools provide the organizational aids to the rather unmanageable amount of resources available on the Internet. The integration of independent resources, such as Internet laboratories, into a uniform, platform-independent environment will enhance teachers' ability to compound desired resources into course folders. At the same time, it enables students to easily navigate between the different resources (individual experiments, instruments, simulation tools, texts, etc.) within the same learning environment.

ARCHITECTURE

The current Lab-on-Web system [3] is based on several commercial software products, which has been necessary to secure an efficient development process, to incorporate functionality needed for easy maintenance of the system, and to achieve a user friendly environment for the clients. The Microsoft Server 2003, which defines the basic architecture, incorporates built-in features to handle laboratory requests. Among these is the HTTP serving Internet Information Services (IIS).

The design of laboratory software has emerged as an important issue due to the cost of maintenance and the need for robustness to large number of requests [4]. Early versions of laboratory software architectures were small and did not pose a challenge for programmers. With increased functionality and complexity, in response to needs for interoperability across operating system platforms, other design strategies must be adopted.

Web Services, as a layer between the laboratory application layer and the presentation layer, is a way of making the system expandable. By introducing this 'proxy' layer between the execution logic in the laboratory application and the user interface, applications acquire properties that are suitable for expansion and atomicity. When defining interfaces for this application, the underlying logic is abstracted and provides a structured way of expansion through a well defined interface. The implementation of such a structure is illustrated in Figure 2. All communication needed to bring information to the front end (i.e., the Web Application) from the logic and information repository, passes through the Web Services interface. Requests for Web Services are directed from IIS through an ISAPI extension and to a .NET framework Web Service executing library.

When utilizing Web Services this way, we acheieve another important property, which is independence of presentation. Whether the presentation layer consists of HTML, an LMS, or a general Content Management System (CMS) is irrelevant as long as the presentation layer conveys the information contained in the laboratory through the Web Services. Any of the presentation techniques can be utilized when the logic is encapsulated within Web Services. The benefit for the developer is that the layer can be utilized in most operating systems and programming languages without rewriting code.

A range of different utilities are connected to the laboratory through Web Services interfaces. Among these are a plotter and a version of the AIM-Spice circuit simulator [5-6]. Another benefit is that clients can select experiments from different hosting locations, using a 'Universal Description, Discovery and Integration' (UDDI) directory, sometimes referred to as a 'Yellow-page' function, to compile course content according to their specific requirements. When an experiment has been performed, the XML formatted results from it can be passed on to the simulator for interpretation and simulation. To view the combined experiment/simulation plot, the updated XML results are submitted to the plotter service, which returns a URL where the plotted result is posted

SECURITY

Security is of prime importance for laboratories that support remote access via the open Internet. The authentication scheme in the laboratory is of a challenge-response type [7]. When designing a large enterprise-scale software system, the security aspect is a significant component. Owing to the widespread use of Web Services on heterogeneous systems, standards have emerged that emphasize how to achieve a uniform platform for security on the scale of Remote Method Invocation (RMI). In our eMerge network of collaborating laboratories, only small amounts of sensitive data exist, which include simple personal information and passwords related to login procedures. This implies that most of the RMI messages have to be authenticated but not encrypted, which would have required a more rigid implementation.

A higher level of security would be to use a more standardized method such as the Oasis Web Services Security (WSS) standard (March 2004). It provides a framework in which SOAP (Simple Object Access Protocol) requests can be authenticated and authorized. To authenticate the SOAP messages in WSS, one might use public key infrastructure (PKI) with certificates (X.509).

USING THE LABORATORY

A common way to access and use the laboratory is described here. When a student first comes to the starting page of our laboratory, he will have to apply for an account. This request is mailed to the system administrator who will grant access for qualified persons. When an account is granted, a 'My experiments' folder, where executed experiments can be stored, is established for the student. The student should then look at the different experiments available and decide which experiment to perform. If, for example, the student wants to find out more about the current characteristic of a regular diode, he may start by reading about typical characterization methods and the physical phenomena that take place when voltage is applied across the device. An experiment that illustrates this can be performed and investigated. After executing the experiment, the results will automatically be stored in the 'My experiments' folder. From this folder, raw data can be retrieved or graphs viewed at any time, it is possible to process the data, make comments, make new plots, or perform simulations for comparisons with the measurements.

When performing simulations on test devices circuit equivalents, the simulator will examine the results and find the circuit from which the results stem and list the available SPICE parameters for the actual devices. Some of these parameters may then be extracted from the experiments and others may be adjusted by the user for a best possible fit to the experimental data. For each adjustment, a comparison of the experimental data and simulation can be viewed in a combined plot, such as the diode voltage-current characteristic shown in Figure 3. (In this figure, the deviation between experiment and simulation is attributed to the presence of generation/ recombination processes [6], which can be included in the simulation by adjusting appropriate parameters.)

LABORATORY DIDACTICS

Traditional laboratory work usually presents students with instrumental equipment that requires a steep learning curve. Users are often exposed to very advanced functionality embedded in these instruments and have difficulties understanding the capabilities or even basic features of the instruments. A common way of learning to use such instruments is to read the instrument manual and get to know the functionality by learning the mapping from knobs to behavior. Instruments can have a complex control layout and abstracting the use of an instrument by only using a few buttons at a time is a typical way of learning how to control it. Most often, basic functions of the instrument can be utilized in a relatively simple way, but they are often hidden in a forest of dials and knobs.

In an Internet laboratory setting, the facilitator (lab or course manager) may seek to make the operation of instruments self-explanatory and self-contained by making available to the students only the functions needed for the experiments at hand. In such cases, the abstractions of the instrumentation should be done according to best pedagogic practices. This would be the case when, for example, the properties of electronic devices and circuits are the subject of a set of experiments, where the focus of the learning process should be directed towards the interplay between theory and experimental findings. In such situations, the complexity of the instrumentation will be an unnecessary distraction.

On the other hand, when the instruments themselves are the subject of the laboratory exercise, the abstractions can gradually be lifted at a pace that gives the students the optimum pedagogical benefit. The process of gradual introduction of more complexity, called scaffolding in pedagogic nomenclature, is very applicable when teaching complex systems. Also, with the ubiquity of Internet and the 24 hour-a-day access to Internet laboratories, students should be encouraged to pursue individual discovery activities, which also should be met with fewest possible restrictions [8].

In general, learning is most effective when students can have interactive sessions with immediate oral or visual feedback. When the focus is on the measurement results, rather than on the operation of instruments, the user interface and the embedded abstractions are of critical importance for the immediate feedback. On the other side, when learning to use instruments, the interaction between the user and the computer-based virtual instrument software is beneficial in itself because of the immediate and rich feedback such systems provide.

FLEXIBLE INFRASTRUCTURE

When designing interfaces such as Web Services for backbone applications, the extensibility is an important issue. The question of whether to opt for flexibility or for fast development always arises when new solutions are considered. In addition, there is a need for the Web Services to be self-contained and – explained. That is, a means of resource discovery and meta-information about the services must be provided so that the automation processes of utilizing these services are eased. Examples of this are schematics layout and information on which restrictions and rules apply to any given experiment.

In our eMerge project, the extensibility is a prime objective because of the nature of our meta-project. Several institutions from different countries and cultures cooperate to enable remote access to advanced laboratory equipment and devices. As a result, flexibility and an intuitive presentation of the protocols used are fundamental for interoperability and export of system solutions to other parties.

Web Services has proven to be an excellent standard for integrating enterprise computer systems across heterogeneous platforms. Hence, this standard creates the necessary foundation to enable different institutions to use their preferred operating systems or applications to access our remote resources. Previously, the only way to access the laboratory was through hard-coded web pages that provided little flexibility in terms of user interface logic and layout. However, basing our system on Web Services, a high level of flexibility is possible, providing the tools for course managers to restructure the user interface of a remote laboratory using the students' native language, and to even modify the experiments to match local requirements.

Another important extension, made possible through Web Services, is to seek integration and interoperability of Internet laboratories with modern Learning Management Systems. Integration between textual resources and such systems has been demonstrated [9], but the integration of interactive tools into these systems is still a challenge. The approach will be similar in some ways, but compared to the case of textual resources, the external resource has to provide a lot more functionality. Among the issues that need to be considered, is the dynamic creation of executables and Web Services at the server side. Executables could be replaced by scripts to avoid compilation, but type and syntax checking can be useful for error detection in the system.

A possible scenario for an LMS is illustrated in Figure 4, where a facilitator is creating an experiment on a remote laboratory server, generating the corresponding user interface and execution logic. The LMS will then behave as a proxy for the Internet laboratory servers and a layout generating machine, creating the user interface in accordance with the user interface standards of the LMS system at hand. A complete laboratory course can be compiled by selecting modules from several Internet laboratories. Hence, the integration of independent resources, such as Internet laboratories, into a uniform, platform independent environment will enhance teachers' ability to compound desired resources into course folders. At the same time, it enables students to easily navigate between the different resources (individual experiments, instruments, simulation tools, texts, etc.) within the same learning environment. A thesis on this scenario is currently under investigation [10].

DISCUSSION AND SUMMARY

Lab-on-Web is an ongoing project, which has demonstrated new and flexible ways of disseminating course material, in particular laboratory experiments, over the Internet. The system is still expanding and new solutions are being applied continuously. As the Web Services technology matures, we will see the adoption of more interconnections and remotely accessed hardware resources. To this day, usage of our Internet laboratory system is open to everyone and can be used for measuring and characterizing semiconductor devices and circuits ranging from single diodes to small-scale CMOS circuits.

The new Web Services interface is language and platform independent, which also makes Lab-on-Web accessible for further development from external, trusted platforms, enabling educators at other locations to adapt versions of our experimental package to their specific needs, without the cost of maintenance and hosting. Another benefit is that educators can select experiments from different hosting locations, using a UDDI directory to compile course content according to their specific requirements. With proper authorization, the user may proceed to access a resource, causing the corresponding Web interface page to be enabled in the portal, through which all communication between the user and the resource will pass. Lab-on-Web can be accessed at different levels of assigned trust. The services can be offered with rigid fault detection where a non-trusted operator is able to perform experiments with high-level procedures that protect the equipment from misuse. On the other hand, a trusted operator may be enabled to use low-level access routines to adapt user interfaces of the experimental set-up to provide their own style and look, which may vary from those defined by the host organization. It is possible even to make reconfigured versions of the experiments themselves.

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FIGURES AND TABLES

FIGURE 1

LAB-ON-WEB OVERVIEW

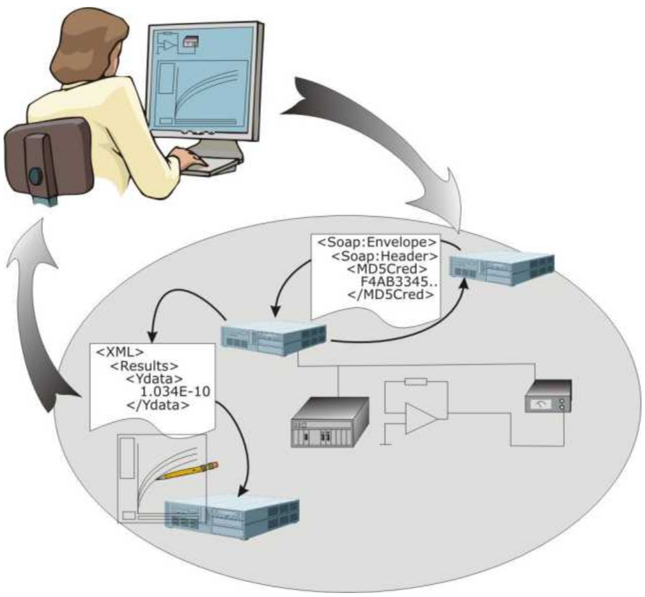

FIGURE 2

LAB-ON-WEB SYSTEM STRUCTURE

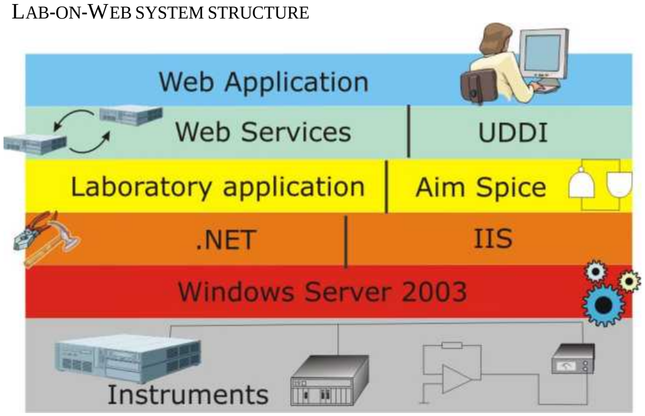

FIGURE 3
EXAMPLE OF A DIODE I-V SIMULATION, WITH THE RED EXPERIMENT AND THE BLUE SIMULATED OVERLAY PLOT

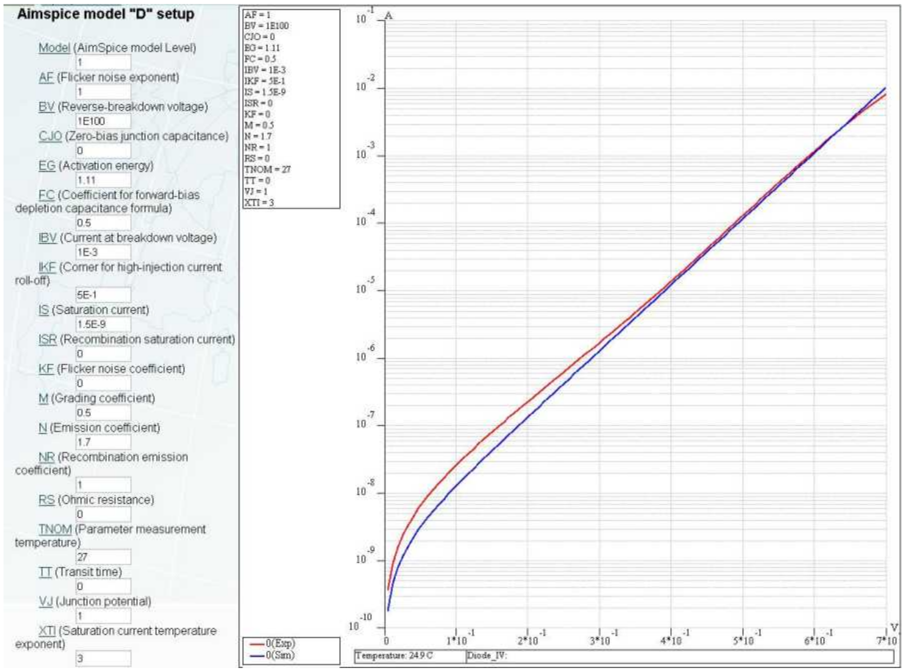

FIGURE 4
LABORATORY INTEGRATION WITH LMS