Highly Configurable Low Cost Remote Laboratory with Integrated Support for Learning: Software and Learning Support

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***Abstract*—A highly configurable remote laboratory system has been create by the authors as a long running project. This paper presents the current version of the software and automated learning support facilities that are parts of this system. The software for the remote laboratory system is created in order to facilitate initially simple, but later on more complex pedagogic support for students using remote laboratories. Current version of the software system includes facilities to limit unwanted behaviour, particularly where students utilise a trial and error approach. The system utilise a batch processing where the aim of the system is to complete all requests within seconds, giving the students the feeling that they have full control over the experiment all the time even when they share it with ten, twenty or more other students.**

***Index Terms*—E-learning, configurable remote laboratory, pedagogic support.**

I. INTRODUCTION

Laboratory exercises are an important part of engineering education, and should aid the theoretical understanding, as well as give hands-on experience for the students[1]. Running laboratories requires significant resources from the institution and is time consuming for the students. Therefore, it is a current trend in engineering education to transfer these laboratories into remote controlled laboratories that can coexist with the vast developments of online learning offerings. A number of examples of remote labs using premade software environments exists, many of which use LabView[1,2], while other use different development tools and platforms, like[3] with Matlab.

The authors have over a number of years worked on implementation and use of remote laboratories for learning, and support for learning at university level. Most work in the area of developing remote laboratories has focused on functional performance as seen from an engineers' perspective: number of functions to perform, similarity to the physical laboratory it should imitate, scheduling of experiment, development of portals or creating of metadata for learning objects for these remote labs, as in iLab[4] and Lab2Go[5]. A significant difference between the systems presented in the above referenced publications and the system presented in this article is the software controlling the hardware and the web server, or the environment that the students should benefit from. The focus for the development is the constructs needed to support pedagogical aspects like adaptive individual feedback.

A student doing a laboratory exercise in a traditional setting, i.e. physical laboratory, will typically have immediate access to a supervisor in the laboratory, giving feedback according to the progress of that particular student or group of students. A remote laboratory is an installation that in most cases will be available for the students 24/7, anywhere in the world, and a user of the remote laboratory will probably not have access to a supervisor should they run into problems. This means that the software must facilitate transfer of information on each user's usage of the remote laboratory and the results obtained from the laboratory experiment for later supervisions, alternatively a system with automatically generated adaptive feedback can be envisioned. An example of the user interface is a remote experiment shown in figure 1.

A. The use of remote labs for learning

The authors are of the opinion that socialisation and collaboration is an important part of learning. The remote laboratories presented in this paper does however not include any support for multiple users in collaboration, like in [2]. Such multiuser support is planned for in a future version.

Remote laboratories has emerged as a valuable tool for teaching both simple but particularly difficult subject matter and it offers the opportunity to perform real time experiments with both expensive and easily breakable laboratory equipment. The pedagogical effectiveness of remote controlled laboratories has been a subject of opinions, discussion and surveys. Varying results have been reported but in general the students have reported satisfaction .e.g. [3-5]. It is still clear that most students still prefer at least some conventional laboratories and feel

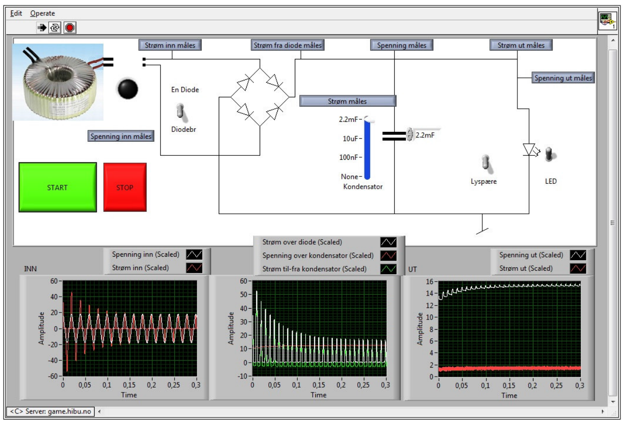

Figure 1. Remote laboratory currently in use at the authors' university.

they learn more or at least gain more tangible knowledge from them. Due to this fact and the varying feedback many universities, including at the authors university, remote laboratories are used as a complement, not a substitute for traditional laboratories.

When using remote laboratories students are typically first presented with theoretical material as a lecture or they receive written material. Occasionally simulations may be used based on the topic, and finally they perform a real experiment either locally or remotely. The aim is to give them a true understanding of complex theoretical matters and practical realities. Conducted surveys demonstrate that students appreciate the autonomy to learn subjects, feel motivated and consider remote laboratories as a good tool for collaborative learning. [3]

II. BACKGROUND

A solution to the problem of students focusing on only troubleshooting, as suggested in the article[6], is to divide the laboratory exercises into two groups. One group for the simpler circuits, where the students gets the hands-on experience as well as circuit understanding, and the other group of exercises for the more complex circuits where the obstacles introduced by the hands-on laboratory is removed in favour of the students' observation of cause-and-effect on these circuits, with reference to the choice of circuit topology and choice of components.

An implementation of the solution presented is done by introducing a remote laboratory, used in addition to traditional laboratories. A remote laboratory is a physical circuit with signal sources and measurement units connected, which is conducted and controlled remotely through the Internet and the experiments use the real components or instrumentation at a different location from where it is controlled or conducted. It is important to distinguish a remote laboratory, which uses real physical components run in real time, from a Virtual lab which uses Virtual Reality, Flash, Java Applet or other software to simulate the lab environment. Running an experiment on a remote laboratory takes time equal to the time it takes to run the circuit in real-time. For most circuit types, this is done in a fraction of a second. This combined with the users being able to change component values by clicking buttons in a web interface, gives the students the opportunity of running the experiment several times in just minutes, allowing for very deep investigation of the effect of different component values.

The motivation for, and the use of remote laboratory in the context of this article is somewhat different from what is found in most previous implementation,[7-10], were the motivation is to offer access to laboratories that would otherwise be inaccessible . The remote laboratory is now used as an addition to, and not as a substitute for physical laboratories. This is an important distinction as the physical laboratories give training in skills not possible to perform in a remote laboratory: doing connections, getting the feel and touch for components, feeling the temperature as the components heat up and, if something goes horribly wrong, smell the smoke of components.

A. *Remote lab with pedagogic support*

The work in the community on remote labs is shifting toward a focus on how to integrate remote labs into learning. Our work is focused on the next step in this evolution: How to support learning and utilize pedagogical and games based techniques in remote labs. The key to achieve this is to look at the software controlling the remote laboratory in the context of pedagogy. As the supervisor is removed from the scene in the transition from physical to remote laboratories, the remote laboratory environment must facilitate the student-teacher interaction in a more or less automated manner.

A list of requirement for the software controlling the remote laboratory environment is created and serves as the basis for the implementation. The focus for these requirements are set on ease of setup, access and readability of the environment, points for integrity of the hardware and protection from misuse are also included. A significant effort is also committed to describe the system requirements for learning support.

The authors has identified that the main shortcoming of most of today's remote labs are a lack for support for learning. Software like LabView and Matlab are tools built for a specific purpose. The configuration options for these tools are limited, particularly when it comes to adding in pedagogical support, a necessity in a learning situation where the tool is used without any other support.

B. *Getting students motivated*

One challenge educators is facing today is that young people are not always eager to do difficult things. The main two choices are then either force them or (an alternative temptation when profit is at stake) lower the requirements for a pass mark. For the gaming industry neither of these are an option, people cannot be forced to buy and play the games, and, in general, players do not want the short and easy option. For educators, this raises an interesting question: "How do game designers manage to get new players to learn their games which are often long, complex and difficult, and even pay for the privilege?" An answer provided by Gee[11] is: "The answer, I believe, is this: the designers of many good games have hit on profoundly good methods of getting people to learn and to enjoy learning." He goes on to claim that "Under the right conditions, learning, like sex, is biologically motivating and pleasurable for humans". This may be regarded as an extreme view, but it is an observable fact that at times learning can be a pleasurable experience.

Additionally it is important that students adopt a deep approach to learning and not just a surface approach. Deep learning involves the critical analysis of new ideas. It requires the student to link new topics of understanding to already known concepts and principles, and leads to a better understanding and long-term retention of concepts so that they can be used for problem solving in unfamiliar contexts. Deep learning requires the commitment of time and effort. The gaming industry have invested heavily into getting players to commit the necessary time and effort to master their games, the challenge for educationalists is to tap into the same feelings, getting students to devote the same time and energy into learning as they do to playing games in the evenings.

C. *Constructivism, assessment and deep knowledge*

The theoretical argument for constructivism is that deep knowledge and long-lasting knowledge is more likely to arise from constructivist learning environments. The perceived benefits of a constructivist learning environment include absorption and synthesis of facts, linking the knowledge of facts with understanding of other knowledge domains, the enhancement of collaborative/cooperative skills and time.

One of the key points of constructivism is to get the students involved in the process, and give the tutor the role of facilitating and supporting learning. Experience has shown that most students will, after some initial misgivings, elect to follow the active learning route and actively be involved in the learning process. The rationale for this is that it is simply more enjoyable.

D. *Keeping learners active*

Students learn more, and enjoy themselves more when they are actively involved, rather than just passive listeners.

Passive mode learning is the easy option for the students in the short run, everything is prepared and they just sit back and let it wash over them. Students who are not brought out of this passive state will usually learn little of the material thus presented. Lecturers/Tutors and students will tend to blame each others for the poor results in the assessment. The key here is to activate the students, and keep them active through learning activities.

Csikszentmihalyi[12] introduced the concept of flow, through a study of people involved in activities such as rock climbing, chess and dance in 1975. He describes flow as a state of complete absorption or engagement in an activity and refers to the optimal experience. According to flow theory, flow can occur when an activity challenges an individual enough to encourage playful, exploratory behaviours, without the activity being beyond the individual's reach. Flow has been shown to have a positive impact on learning, see Galarneau and Kiili[13, 14].

Many people are advocating taking the hard work and discipline out of learning. However, we would argue that this is not the answer. Rather, what we should be doing is finding tasks that will harness the passion of the student to the hard work needed to master difficult material

Therefore, one main aim for us as designers of learning material is to design content in such a way as to allow different students to obtain the state of flow, irrespective of their different knowledge and abilities.

III. REMOTE LAB SETUP

A. *Initial setup of the remote laboratory*

The project described here includes the setup of a framework for implementing remote labs. An outline for the requirement for such a framework for remote laboratories have previously been published[15]. A test implementation of a remote laboratory is set up. This test implementation embodies the basic requirements set out for the framework: Simple setup and support for multiple browsers i.e. use of a web page that does not require external installed components, graphical display, and setup of experiment on client without the control of the experiment whenever possible. The implementation utilizes a generic structure shown in figure 2.

The remote laboratory setup utilizes a standard web server with a webpage based on java script to setup the experiment. The experiment is then submitted to the server by the user via the web client. The server maintains a queue of experiments that needs to run. In the current set of implemented experiments the runtime for a single experiment is 1 second, so this queue is mostly short or

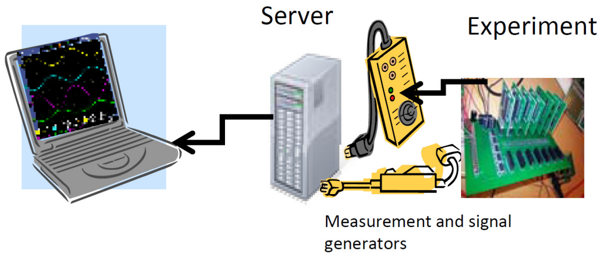

Figure 2. Generic structure of a remote laboratory setup.

even empty and the wait time for running is equally short. Once the experiment is admitted to the queue the web client is updated with an estimated waiting time. Once the experiment is complete the data obtained is temporary stored in a database and then transmitted to the web client, on a web page utilizing java script and AJAX setup when data is loaded, as it is required.

B. *Automated support for students*

The main aim of the whole project described here is to create an automated system to aid the students while they work on a remote laboratory. The argument for an automated system is initially twofold, To handle the amount of students using the system will overload a human tutor, in addition students tend to use the remote laboratory at all times both day and night.

The automated system is still under development and at the current time only handles some basic behaviour:

- If a student submits a series of experiment in rapid order, the system will interpret this as an attempt to run a trial and guess solution. Currently, performing 5 attempts within one minute is defined as a trial and guess approach. When the system then detects a trial and guess approach, it will block further attempts for one minute. In this state the system will not display any help messages as described below.
- A set of values of components can be predetermined, the system can detect if consecutive attempts by the students are converging towards these values. If the values are not getting closer in some of the last 5 attempts the system will display a special help message.
- In experiments like an amplifier the system has the ability to compare the input and output signal and in the same way as with the consecutive component value changes, detect if an specific amplification is achieved or not, or if the students consecutive experimental setups converges towards this or not. As before a help message can be displayed if the student is deemed not to make any progress.
- On amplifiers or similar circuits the system can also compare input and output signal to look for distortion or phase change, if this is desired by the instructor. In the same way as before, a help message can be displayed if such problems are detected and the students does not make any progress in solving them.

C. *Batch running experiments to avoid queue*

As described previously, batch processing is the basis for the scheduling of experiments in the software system implementation in this project. The batch processing is not presented to the students in the traditional form, where they add experiments and then expect to return for their results the next day or in a few hours. The aim of the batch system in this project is to complete all or close to all requests within seconds, thereby never give the students a feeling of batch processing, but rather giving the students the feeling that they have full control over the experiment all the time.

The students will setup the experiment and submit it for a run on the hardware. The execution of the experiment will take about a second. All data will be captured and presented as graphs, which can be seen and manipulated by the student afterwards. The system will typically capture all information that is possible to capture even if the students does not elect to do so, thereby giving the option of examining signals post experiment that would otherwise require a rerun.

Figure 3 shows an example that has been in use by the students at the authors' university for some time demonstrating the selection of signals post experiment. All three graphs on the right side of the experiment window can be configured and all signals are available for all. In the current example the signals selected are Vin and Vout for the top graph, VB, Ve, and VE2 for the middle, and just VE for the bottom. The graphs will automatically rescale for best viewing.

D. *System overview*

The system design consists of multiple software and hardware elements.

The hardware controller part of the system is in charge of handling all the different hardware components and setups for each different signal generator or sampling equipment used for the various setups. The hardware and devices in figure 4 are the physical parts of the experiment. This setup is described elsewhere[16].

The effort involved in setting up all the software parts including a simple system controller was fairly small, as standard components and design patterns was utilised. The main effort was put into configuring the hardware layer to run with multiple sets of hardware and to design a general system that can handle future development and plugins for, what is the main part of the project, intelligent support for the students while they are engaged in using the remote laboratory for learning. The system controller has the option of calling a separate subsystem implemented in any language or technology. Currently the logic is simple with just a trigger on submitting too many experiments in a short time. If the system detects unwanted behaviour the system informs the user using the page shown in figure 8. Unwanted behaviour in this context is defined as a trial and error approach, where the students send multiple experimental setups to the system in the span of just a minute.

The frontend visible by the users are the web server. The web server is in charge of presenting and maintaining the user identification via a login system, shown in figure 5. The web server is also responsible for:

- presenting the screen listing the available experiment to the users, as shown in figure 6.
- acquiring the select parameters for running the experiment from the user as shown in figure 7.
- presenting the results of an experiment to the user.

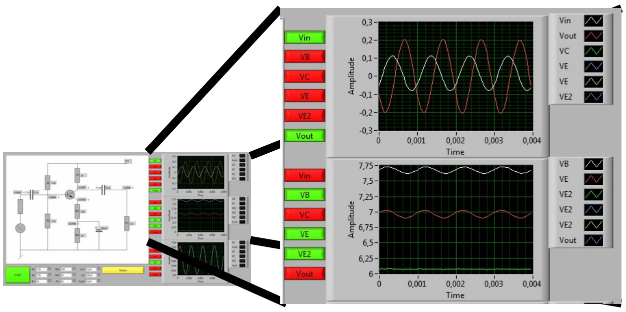

Figure 3. Example of remote laboratory with selection of signals.

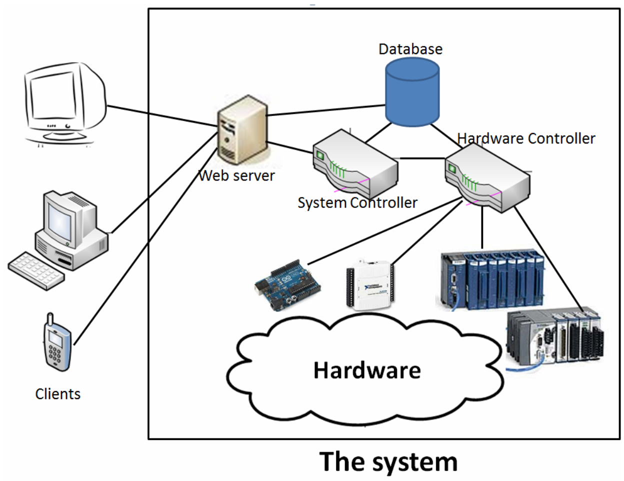

Figure 4. Overall structure of the system.

All this is achieved via what is now a fairly standard web solution with a combination of using both php and java script running on the server and client side.

The database is used to store information about users, what experiments that has been run including what parameters was used to set up these experiments, and currently also the results of these experiments. There is a need to set up maintenance tasks that will be in charge of clearing out old data from this database, as the expectations is that the amount of data will quickly be both too great to handle, and will over time be of little interest. The maintenance part is currently a simple and crude mechanism deleting data from the oldest experiments as space is required in the database.

A typical experiment run is performed as follows: The user logs into the system as shown in figure 5. The need to login stems from the requirement that the tutor should be able to know who-does-what in the laboratory. This in turn is done in order to give meaningful feedback/tutoring to the individual student. In the webpage shown in figure 6, the user selects one of several remote experiments. In the example given here, the user selects the BJT amplifier laboratory. Now, the user can set up the experiment as shown in figure 7. This user interface focus on easy-of-use and resemblance to the schematic which the students are presented in the textbook for the module for which the laboratory exercise is performed. The component values are also conveniently placed immediately at the side of the schematic, giving the users easy access to, and a good overview of the component values selected. An alternative could be to use life-like replication of the instruments the students can find in the laboratory, but as stated in previous sections, the aim of these laboratory exercises is to

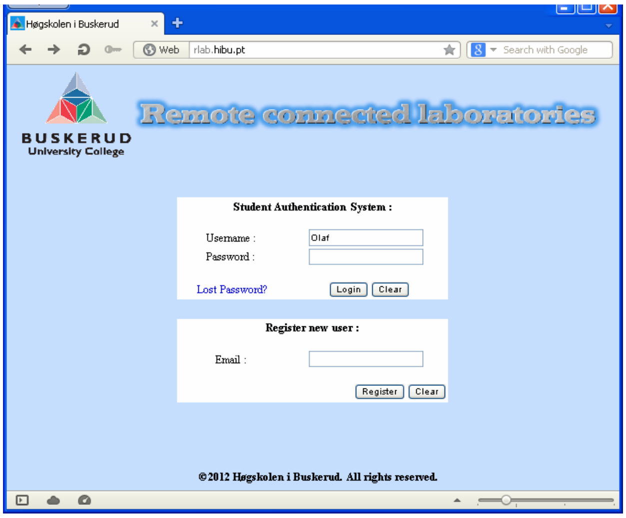

Figure 5. Loginpage.

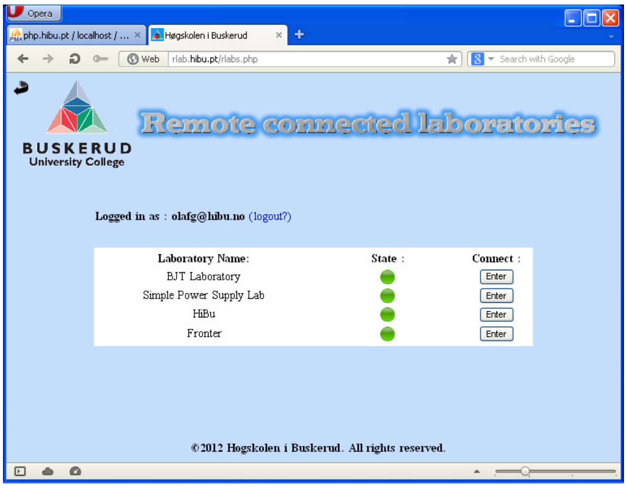

Figure 6. Presentation of available experiment to the users.

help the students create a link between the theory they learn in class, and what actually happens in the circuit when power is turned on and a signal is applied to the circuit. The idea now is that the user interface should allow the users to quickly change component values, possibly after doing the calculations required, without their train of thoughts being interfered by tedious disconnection and re-connection of components on a breadboard. If, however the user misuses the simple re-selection of components to perform a trial-and-error approach to the experiment, the user is faced with the screen shown in figure 8, stating that a different approach should be made. It is left to the user to understand that this approach involves performing calculations before setting new values for the components.

IV. CONCLUSION

A system is presented that is designed to stop unwanted behaviour where students just utilise a trial and error approach. The system also utilise a batch processing where all requests are completed within seconds, thereby never give the students a feeling of batch processing, but rather giving the students the feeling that they have full control over the experiment all the time.

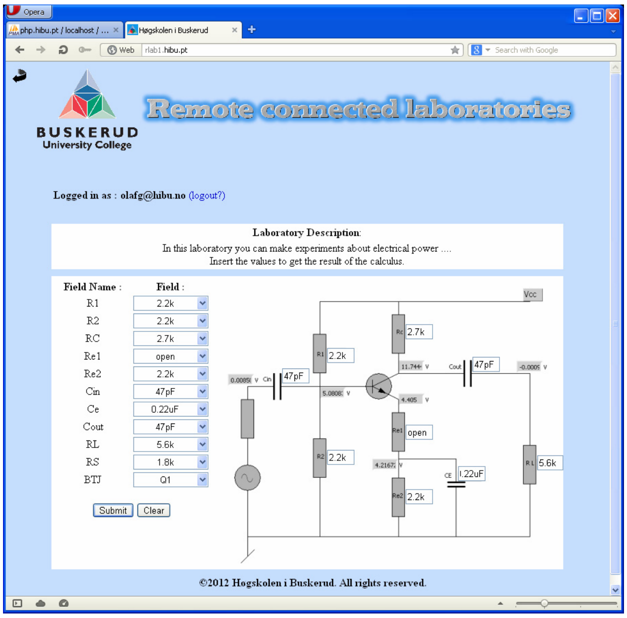

Figure 7. Presentation of an experiment for a user.

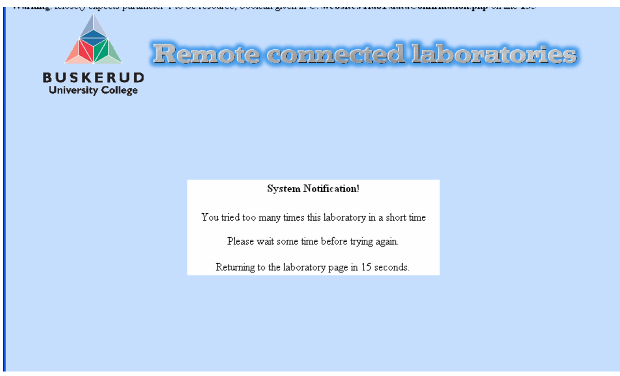

Figure 8. Stopping unwanted behaviour in users.

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