Introducing Remote Laboratory Equipment to Circuits - Concepts, Possibilities, and First Experiences

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Introduction

This innovative practice work-in-progress paper describes a case study and the connected evaluation in which a ready-to-use remote laboratory system for electronic laboratory work, called VISIR (Virtual Instrument Systems In Reality), is used in and adapted to an existing circuits course over one semester in the College of Engineering at the University of Georgia (UGA).

Even though remote laboratories, defined as experimental equipment that can be used from a distance via the internet, have been around as a technical solution in education for several years, these technologies are not yet widely used in higher engineering education. This statement is made in comparison to the opportunities made possible with remote labs. Considering that remote labs are represented as equipment that can solve location, time and capacity constraints in laboratory education, this is surprising as many educational institutions suffer from exactly such constraints. Existing literature shows that classroom laboratory solutions are mainly stand-alone solutions which require physical equipment and cannot be used synchronously among several institutions [1], [2], [3]. In this context, the VISIR system represents an exception [4]. The introduced VISIR system was developed a few years ago and it presents both an economical and pedagogic solution for constraints in context with laboratory education [5]. The system has been successfully installed by several universities (and university alliances) around the globe; e.g. the European PILAR federation (Platform Integration of Laboratories based on the Architecture of VISIR) [6].

In the present study we used a system in class, which is physically located at the University of Deusto in Bilbao, Spain (see Fig. 1). The laboratory system itself is accessed through the website of LabsLand, which is a startup company dedicated to developing remote labs and offering access to the technology (see www.labsland.com). Here we will explain the VISIR system more in detail. This is ensued by details on how this system was introduced in a circuits course in the College of Engineering at UGA and how this has been evaluated in its first year.

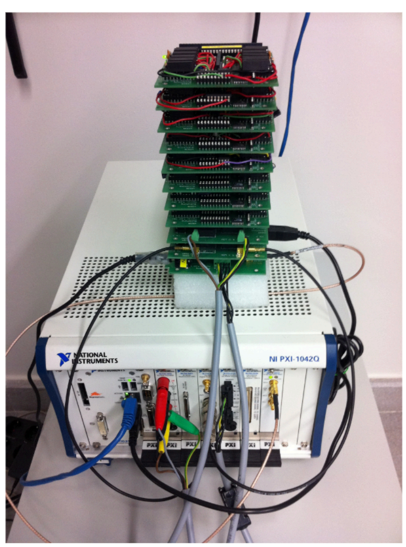

Figure 1: VISIR remote lab set up at University of Deusto, Spain

The VISIR remote lab

The VISIR Open Lab Platform, developed at the Department of Electrical Engineering (AET), the Blekinge Institute of Technology (BTH), Sweden, is an architecture for improving existing types of hands-on labs in the area of electronics and circuits. It features remote access with preserved content in order to supplement and increase the accessibility and the capacity of standard lab equipment. A unique web-interface duplicates hands-on equipment and, hence, gives students a feeling of being in the physical hands-on lab [7]. The VISIR system basically consists of four different parts: The web-interface, the equipment server, the measurement matrix, and the switching relay matrix.

The VISIR workbench is equipped with a web-interface enabling students to recognize the benchtop instruments. These include: a virtual breadboard, a multimeter, and an oscilloscope which can be used on the student's computer screen (see Fig. 2-4).

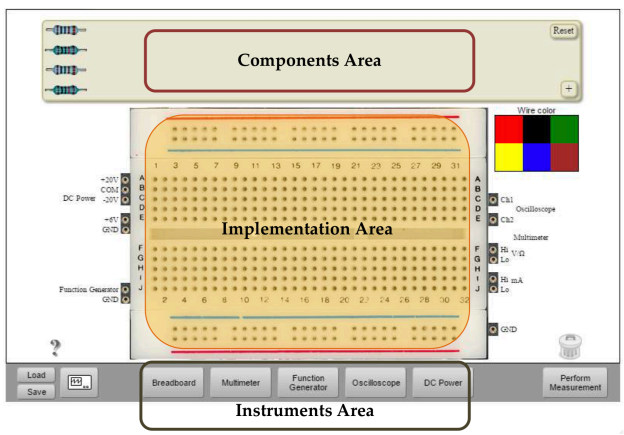

Figure 2: Web-interface showing the breadboard and main areas for interaction

Figure 3: Digital multimeter front panel

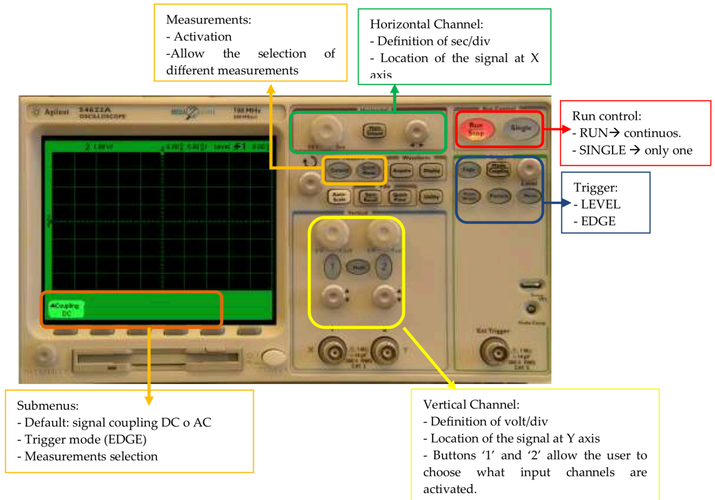

Figure 4: Main functionalities of the digital oscilloscope

The equipment's goal is to reproduce tactile learning by emulating the required operating functions, such as moving components and rotating instrument knobs. Hence, in VISIR tactile learning has been replaced by a tele-manipulator which the student can control virtually. To begin, the user creates a circuit in the web-interface and defines the settings of the instruments. This is accomplished by creating wiring and building components on the virtual breadboard. After pressing the 'Perform Experiment' button, the data is sent to the measurement server and the equipment server.

The measurement server acts as a gate-keeper that controls the commands passing from the web interface to the equipment server to prevent dangerous circuit designs and protect the instruments. It is programmed by 'max list' files, which contains the maximum component values and instruments adjustments for each experiment and describes the allowed circuits in the platform. The equipment server is connected to the relay switching matrix, and both are controlled by this server (which is coded in LabVIEW). It receives the commands from the measurement server over TCP/IP to the experiments on the real instruments in the switching matrix. A 'component list' file is coded into the equipment server to define the components physically installed on the matrix. After validation from both servers, the desired circuit is configured on the matrix and the experiment is performed in fractions of a second. The result is returned to the user and is shown on the web interface.

A time-sharing algorithm enables this procedure to be done by many users at the same time; hence, to experiment simultaneously (i.e. the workbench is equivalent of a laboratory equipped with many traditional workbenches). Since the experiment is performed in fractions of a second, the overall number of users can be high. It is estimated that a single VISIR would be able to handle a class of 40 students, the maximum number of students at a lab at UGA. As there have been numerous publications about the technical side of VISIR we are referring at this point to the existing literature (e.g., [8], [9]). Experiments in three different areas of circuits design can be performed by using the system. Depending on the area, different equipment parts and components for circuits building are offered to the use. In the area of analogical electronic experiments, the user is able to build circuits with resistors, capacitors, diodes, operational amplifiers or transistors and check their behavior with the available instruments. Performing experiments with resistors includes activities like connecting, measuring and discovering how to combine resistors in series and/or parallel combination. Users can test all combinations that can be built with 2 resistors of 1k Ohms and 2 resistors of 10k Ohms and measure the equivalent circuit using the digital multimeter. The third area covers performing experiments in context with Ohm's and Kirchhoff's laws. That includes building and measuring any circuit using 2 resistors of 1k Ohms and 2 resistors of 10k Ohms, feeding the circuit with the +20VDC source and using the multimeter for measuring the voltage at any point in the circuit and the current at the beginning of each branches.

VISIR in circuits at the University of Georgia

VISIR has been introduced to an existing circuits course with around 18 students, who used VISIR in conjunction to existing physical hardware. The introduction of VISIR theoretically opened up the opportunity to the students to (1) independently prepare themselves before class with the help of the remote equipment, (2) actually do the in-class experiment online instead of hands-on, and finally (3) recap concepts learned in class by autonomously performing additional experiments. Even though the students did not take advantage of all three options to the same extent, this paper will discuss the students' experiences based on this semester's usage.

In particular, VISIR was deployed to help with topics that have been historically challenging. First, VISIR was used as a training tool for breadboarding skills. Students often confuse the rows and columns on a breadboard that are connected. The VISIR provides immediate feedback if the configuration is wired correctly. This one on one interaction allows for successful skill building without the potential stigma of having to ask for help and also provides an environment where the consequence of failing is not linked to destroying hardware. Secondly, the VISIR was used to build skill in implementing operational amplifiers (op-amps). Op-amps are wonderful devices for implementing a variety of signal processing applications, but also have a steeper learning curve. Operational amplifiers are active elements meaning they require external power. This added wrinkle increases the potential of poor implementation that can lead to "smoking the op-amp". In our experience the resulting smell has never failed to create a stench in any size classroom. Using the VISIR, no op-amps were destroyed, and rather students could take the time to evaluate what aspects of the configuration are incorrect.

All in all, 174 experiments by 18 users have been done in course context using the VISIR system:

- Analogical electronic experiments: 129 uses
- Experiment with resistors: 31 uses
- Experiment Ohm and Kirchhoff Laws: 14 uses

The LabsLand environment gives the opportunity to examine the lab uses with regard to time of the day and day of the week, on which the experiments have been conducted. Fig. 5 shows the respective data. The data clearly shows, that the students have been using the tool mostly in direct context with the lab class on Wednesday's afternoons. Hence, most of the experiments have been conducted shortly before or even during class time. Nevertheless, the data also shows, that experiments also have been carried out late in the evening on Tuesdays or even on Sundays. This supports the aim to give the students more flexibility in performing own experiments and give them access to such equipment at uncommon times of the day or week. Even though the numbers are not overwhelming high, there can be a demand detected.

Uses per time of day

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
00:00	1		1				
01:00							
02:00							
03:00			3				
04:00							
05:00			1				
06:00			2				
07:00							
08:00		2	2				
09:00	1	5	3				
10:00			1				
11:00	4	1	1				
12:00		5	1				
13:00	2	1	42				
14:00		10					5
15:00		10					4
16:00		5			3		
17:00		1	5				1
18:00	2	1					2
19:00	2	1					1
20:00		5					
21:00	1	3	2				5
22:00		9			2		2
23:00		13					

Figure 5: Lab usage timing retrieved directly from the online system

Evaluation method and results

Data has been collected over one semester using mainly an online survey, which the students were asked to fill out after the course has ended at the end of the semester. Apart from several closed questions, the survey also included open questions in order to get a broader impression on how the students think about VISIR in particular and remote labs in general. At this point it has to be mentioned, that the presented work is still work in progress. This had direct impact on the evaluation methodology in terms of tool robustness (we mainly adopted tools used at other locations) and survey return rate.

In order to develop the evaluation tool, we took into consideration, that three different perspectives for lab evaluation play a crucial role for getting a sound overview. These perspectives are the technical perspective (focusing the technology and the equipment), the individual perspective (focusing on the individual learner and his competence development), and finally the instructional perspective (focusing on the lab's embeddedness into the overall course and instruction) [10]. In addition to that, it has to be stated that so far, no evaluation tool for remote labs has been developed, which is widely accepted und used. Hence, at many institutions several different tools are in use and in many cases the tool itself is object of research. Taking the above-mentioned evaluation perspectives in to consideration the evaluation tool introduced from Marchisio et al. seemed to provide a good first fit four our study [11] . With all in all 20 items the authors gained student feedback on basis of the students' self-perception for the dimensions perceived learning (see individual perspective), perceived teacher guidance (see instructional perspective), technical restrictions (see technical perspective), and VISIR acceptance (see individual perspective again) [11]. In order to provide an even better fit for our study at UGA, we adopted that survey, took two items out, added fifteen items, and allocated them to five dimensions (Perceived learning, VISIR acceptance, immersion and usability, perceived teacher guidance, time and technical restrictions). For the additional items we took inspiration from other published studies on VISIR and other remote labs [12], [13]. The survey with 33 items has been send out to the students in an online version after the course's last session. For the survey development and data analysis the survey tool from Qualtrics® has been used. For the survey the students were asked to rate their personal level of agreement or disagreement to each item on a 5-point Likert-scale, 1 being totally disagree and 5 fully agree (items 10, 30, and 32 are phrased negatively, so that a response with 1 or 2 can be regarded positive in the study's sense). The survey system randomized the order, in which the items were presented to the student. From six students we received a full set of answers, which form the basis for the following results analysis. Table 1 shows the 32 items in its respective dimensions and the results.

Table 1: Online survey dimension, items, and results (N=6)

	#	Item	Min.	Max.	Mean	Std Dev.	Var.
learning	1	Using VISIR helped me understand better some issues in the subject.	3	4	**3.67**	0.47	0.22
	2	I tried the experiments several times when I found that results were strange.	3	5	**4**	0.58	0.33
	3	I think I can solve many real electricity problems.	3	5	**3.83**	0.69	0.47
	4	I could use the scientific concepts to explain the results of the experiments.	4	5	**4.17**	0.37	0.14
	5	Using VISIR enhanced my ability to apply theoretical concepts to practice.	4	4	**4**	0	0
	6	Using VISIR strengthened my practical skills.	2	4	**3.67**	0.75	0.56
	7	Using VISIR strengthened my theoretical knowledge.	2	4	**3.33**	0.75	0.56
VISIR acceptance	8	I was able to use VISIR 24/7.	3	5	**4.17**	0.9	0.81
	9	*I would rather make traditional experiments than use a remote laboratory like VISIR.*	*2*	*5*	***4.17***	*1.07*	*1.14*
	10	I shared the VISIR experiments with acquaintances who do not belong to the college.	1	2	**1.5**	0.5	0.25
	11	I have always shared the results with my fellows.	1	4	**2.67**	1.11	1.22
	12	I was less afraid of damaging VISIR system than when I work with circuits in the traditional lab.	2	5	**3.83**	1.07	1.14
	13	I carried out experiments which were different from the ones I was allocated.	1	3	**2**	0.58	0.33
	14	I wish I had remote labs for other subjects.	3	5	**4**	0.82	0.67
	15	Laboratories like VISIR serve as a complement to hands-on labs.	3	5	**4.17**	0.69	0.47
	16	While using VISIR, I was motivated to continue carrying out the experiment.	2	4	**3.17**	0.9	0.81
	17	I used VISIR more often than I needed to on basis of the assignment out of curiosity.	1	4	**2.33**	1.11	1.22
immersion and usability	18	I think I can handle VISIR well.	3	4	**3.33**	0.47	0.22
	19	I found that VISIR and its devices were easy to use.	2	4	**3.17**	0.69	0.47
	20	Moving between the breadboard page and other equipment and instrumentations pages did not hinder my attention	2	4	**3.33**	0.75	0.56
	21	I can see similarities experimenting with remote labs as with traditional labs.	3	4	**3.83**	0.37	0.14

	22	The equipment and instrumentations in VISIR are identical to their real equivalence.	2	4	**3.33**	0.75	0.56
	24	Although I was far from the VISIR (the real system is situated in Spain), I felt myself to be in control of it.	2	4	**3.33**	0.75	0.56
teacher guidance	25	The instructions for the experiments were always clear.	2	4	**2.67**	0.75	0.56
	26	I consulted the VISIR manual to learn more about the systems.	2	5	**3**	1.15	1.33
	27	I didn't need the assistance of the experiment tutor in most of the activities.	1	4	**3**	1.15	1.33
	28	The objectives of the experiment(s) were clear to me at all time.	2	5	**2.67**	1.11	1.22
technical restrictions	29	*I have had many difficulties with the server and VISIR.*	*1*	*4*	**2.5**	*0.96*	*0.92*
	30	The response time of the system was adequate.	3	5	**4**	0.82	0.67
	31	*I found it difficult to find time to carry out the experiments allocated.*	*1*	*4*	**2.67**	*1.11*	*1.22*
	32	VISIR worked without any problems.	3	4	**3.5**	0.5	0.25

In addition to the closed questions presented in Table 1, the students were asked to answer three open ended questions at the end of the survey. In order to give an overview on the students' response two to three representative answers (in italics) for each item will be given in the following:

33. What have you found most interesting when using VISIR?
    - *"When I initially heard of the equipment I was skeptical, since doing a lab through a website seemed intuitive to me. However, I was pleasantly surprised by the amount of interactivity between the different pages of equipment and the components, and the consistent availability of the lab."*
    - *"The components and measuring devices were very similar to those found in our lab."*
    - *"The fact that you are getting actual results from a real lab."*
34. What drawbacks have you found when using VISIR?
    - *"Personally, I find experimentation through an online resource to be less helpful than hands-on learning. Being able to troubleshoot what is in front of me, rather than on a screen, is also a little easier for me. Additionally, moving components and wires, turning knobs, and pressing buttons, while seemingly trivial, makes a lab more fun and satisfying for me. […]"*
    - *"It was difficult getting started because we didn't have much instruction on how to use it. But once I got the hang of it, I liked it better."*
35. If you could change anything about VISIR and its usage in course contexts, what would that be?
    - *"I think VISIR would be wonderful to use for observations rather than experiments. While I didn't think moving between the pages of different equipment was tedious, I did think moving around the components, aligning the wires, and troubleshooting a circuit was troublesome. It would be much easier for me to rearrange a circuit, or disassemble and troubleshoot it, if it were in front of me. For example, I could tell when my transistor is reversed, because it might overheat, whereas through VISIR I would only be able to determine the problem after meticulously inspecting every component and their orientation. However, for observations I think VISIR would be very helpful, because*

of its ease of access and because there is no need to keep track of components."
- *"There needs to be a much better intro tutorial on how to use it. Especially, if it's for a beginning circuits class where no one has even touched a bred board before."*

Discussion
The first introduction of the VISIR lab to a course in the College of Engineering at the University of Georgia described in this work has to be seen as a pilot study and the main goal at this point is to get a good sense on how to use the system in the local context. This also means that the evaluation results and their interpretation have to be seen as limited at the moment. That comes even more into effect since only six student responses could be collected from the course. Nevertheless, some interesting preliminary results can be retrieved, which could guide future work in that area.

The survey results for the 'learning' dimension in total show very positive results. None of the mean values for any item is below an average mean value of three. Especially, the mean value for item #4 is supportive, as it shows that there has been made connection between the scientific concepts and experimenting with VISIR by the students. This is supported by the rather high value for #2, which shows also shows that the students did question the results and, hence, compared it to expected results. Furthermore, VISIR seems to enhance the students' practical skills on basis of their self-evaluation.

The results in context with the acceptance dimension are ambiguous. On the one hand students liked VISIR (at least as a complement to real labs) and would like to have such labs for other subjects, too (see #14 and #15). On the other hand, there is a clear sign that students would prefer real labs over remote labs for performing experiments. This goes very much in line with the feedback to #33 and #34 and it shows two different lines of argumentation. Even though laboratories like VISIR are a good opportunity for expanding access and lowering barriers for lab usage, they should not be seen as a replacement for real labs but rather as an additional resource. And in this context, it seems to be well received by the students, that they handle with real equipment instead of a simulation in VISIR and don't need to be afraid of breaking the equipment.

Looking at the results for immersion and usability the most promising data set can be seen for #21, whereas the other answers are not really leaning towards one or the other side. However, recognizing that the students do make a connection between real and remote labs has to be seen as a positive result.

The fact that VISIR has been introduced into the course as an additional resource to the hands-on labs and as not much of a tutorial has been given to the students cannot clearly be detected in the results for the teacher guidance dimension. This has happened in parts in purpose, as it was intended to get an idea of how much guidance would be need in addition to the online available VISIR tutorials for the students. This shows that the system is self-explaining to a large extend, even though some students negatively commented on that in #34 and #35. However, the results for this dimension and for the technical restriction dimension show, that there haven't been a lot of problems for the students using the system. This definitely has its cause in the fact that the VISIR system has been developed and optimized for several years now. Hence, the technology has become pretty robust by now and a lot of improvements have been carried out already.

From the teacher's perspective the VISIR provided a valuable resource for non-major students and students who, for whatever reason, have shied away from hardware. Unlike pure simulation software the VISIR provides a much needed "this will actually do something" motif that students are often lacking in pure simulations. The VISIR was able to accommodate two of the most historically challenging skillsets. Moreover, the instructor noticed students seem to complete their labs faster and it seemed to be overall less stress in the laboratory experience due to the introduction of VISIR. However, to this point this has to remain just an anecdotally observation, as we did not record data on that specific aspect. This will be done in future revisions of this study in order to look closer at the VISIR value for the course.

Summing up, this work-in-progress case study actually showed two different main aspects. On the one hand the study can be seen as a proof-of-concept for using a ready-to-use remote lab as VISIR in an existing circuits class. In principal, the first evaluation results and the student feedback are supportive so far, even though the results also show clearly room for improvement. This mainly counts for the connection between the lab usage and the tutoring. Future research will also seek for a deeper understanding of how learning happens in VISIR. In this context previous studies will be considered in order to compare results from the University of Georgia to results from other institutions.

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