Practical Color-Matching Remote Laboratory
Integration and Experimentation

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***Abstract*- As classrooms in higher education become more technologically integrated, remote labs have become a better way to demonstrate concepts in classes that require hands-on experience, such as engineering courses. In concurrence with FAU's Smart Adaptive Remote Labs, one possible experiment that can be used by students who are accessing the software is an LED color-matching remote lab. Using a standard logic design breadboard and kit, students using the experiment would use the remote lab to operate a color matching game using buttons and switches. The end goal is to teach students basic circuit design principles that are being taught in the Logic Design course. This paper presents the online architecture where the color-matching game is hosted, the design of the remote laboratory, and the software developed for the UI.**

Index Terms: Remote lab, php, RLMS, Logic Kit, color theory

I. INTRODUCTION

Online remote laboratories provide a method for students to operate and analyze live experiments from a virtual learning environment (VLE). Higher education courses with STEM focuses can particularly benefit from online remote labs to explain concepts that may be foreign to students learning about topics like microprocessors or circuit design. The Smart Adaptive Remote Laboratory (SARL) architecture provides instructors with a centralized platform to implement multiple remote labs to demonstrate and teach a variety of concepts while students experience hands-on experiments that are educational and accessible [1]. Introduction to Logic Design is a prime example of a course that would benefit from remote labs.

The color-matching remote lab provides a practical, user-controlled experiment that focuses on a fun game to match randomly generated colors with LED light combinations. The experiment teaching users how computers and screens generate any color from red, green, and blue light. It is also a nice introduction to the Logic Design curriculum because this lab does not require the user to have a significant level of technical understanding or expertise to operate.

This value of this experiment comes from the remote lab setup. It is known from independent research papers that the level of student engagement and understanding goes up when a virtual component of the lab is introduced [2]. In the paper cited, the authors acknowledge that the use of fully virtual labs comes with the criticism that in an all-virtual setting, students do not develop laboratory skills. In the hybrid remote lab format, this is not a concern. Remote labs a have also been proven to be an effective teaching tool in situations where there are limited resources such as developing countries. Remote labs serve to promote individualized learning in places that do not necessarily have the resources to cater to every student [3].

II. ONLINE LABORATORIES

Online laboratories have become more prevalent and diverse in higher education as more universities become technologically adapted to today's advancements. These types of labs can be classified based on whether the experiment is real or being conducted in a virtual environment, and whether the experimenter is conducting the experiment live or remotely, as shown in Figure 1.

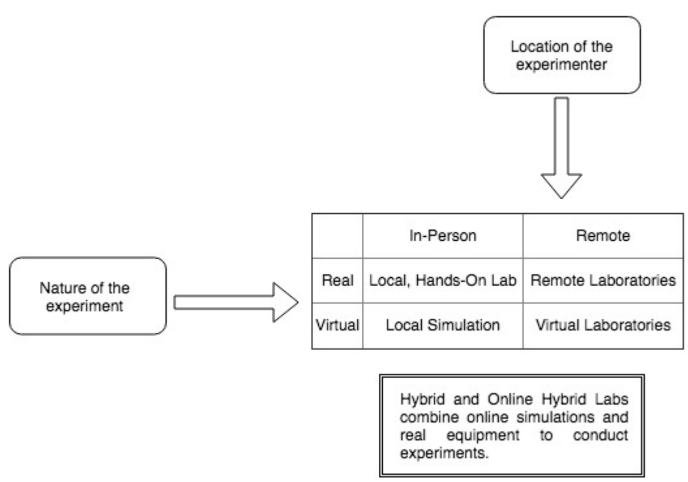

Figure 1: This figure shows how online laboratories fit into the classification of labs in general [3]

Furthermore, online labs can be divided into virtual, remote, or hybrid types.

A. VIRTUAL LABS

Virtual labs are conducted outside of a traditional, physical laboratory and instead run different educational simulations in an online setting. Virtual labs often times are online resources that are supplementary material to the class. Other non-course based resources create virtual, interactive simulations to demonstrate various phenomena and concepts in mathematics, chemistry, physics, and other subjects. For example, researchers that created the Java-implemented Virtual Physics System (ViPS) used advanced simulations and tutoring software that can dynamically adapt to middle schoolers progressing through physics courses. Simple machines such as pulleys were modeled to teach students different concepts, and allows students a greater freedom to manipulate the experiment than if it was in a physical setting [4]. ViPS and other online labs use software and simulations to explain real-world phenomena. However, universities that deploy virtual labs via massive open online courses (MOOCs) may fail to teach the hands-on aspect that is crucial to developing good lab habits and lab skills [5]. Additionally, lab conditions help control many variables that are not accounted for when running simulated mathematical models via a computer.

B. REMOTE LABS

Remote labs are defined as a lab that exists in a physical location, but that are accessed and controlled through the Internet. Remote laboratories are only possible through the deployment of the correct architecture that connects the laboratory setups, to the users, to the LMS that displays the remote labs, and to the administrator running the server. In Brazil, researchers at the University of Santa Catarina have developed remote experiments that can be implemented at a low cost for Brazilian schools that may not have access to funds, nor the space and materials required for traditional labs [6].

These laboratory experiments are set up in a separate location, monitored by a camera whose feed is connected to the Internet. The camera, the experiment, and what the user sees through their interface, all happens in real-time [7]. Users can operate these experiments and obtain similar results to in-person labs. One of the drawbacks of remote labs are that despite having quick access to the Internet, each remote lab experiment can be controlled by one user at a time. Therefore, there will have to be build-in modules that schedule students to work at pre-appointed times [8].

C. HYBRID LABS

Hybrid labs combine online tools and simulations while being operated in a physical laboratory. Hybrid experiments are particularly useful for courses in higher education with challenging subjects like physics, which require technological assistance in order to measure phenomena like magnetic fields. Instructors may opt to have students perform work in a VLE while manipulating tangible lab sets, or merely use online tools to record data while performing the lab in a physical location. Hybrid labs can also combine aspects from two aforementioned laboratories to form complex laboratories that combine advanced simulations from virtual online labs with the ability of remote experimentation from remote labs. Developing these hybrid labs require architecture that can be accessed universally without risking the security of those using the programs [14].

III. REMOTE LABS INTEGRATED TO LOGIC DESIGN COURSE

Introduction to Logic Design is a class offered by the Department of Engineering and Computer Science at Florida Atlantic University (FAU). The purpose of the course is to teach computer science, computer engineers, and electrical engineers the basics of how combinational and sequential circuits. Within the course there is a laboratory component that is fifteen percent of the student's grade. For the Logic Design labs, the university provides a standard lab kit with two breadboards to perform experiments (see figure 2). The class currently has a six-lab setup that goes along with concepts learned in lecture. The purpose of hybrid labs is to make the lab work more interesting and personalized. The current labs are tedious and reflect lecture concepts, but lack any allusion to practical applications. In the current system it is also very easy for students to cheat by allowing their fellow students to copy lab work directly. With a hybrid lab that adapts to each individual student this is not a concern.

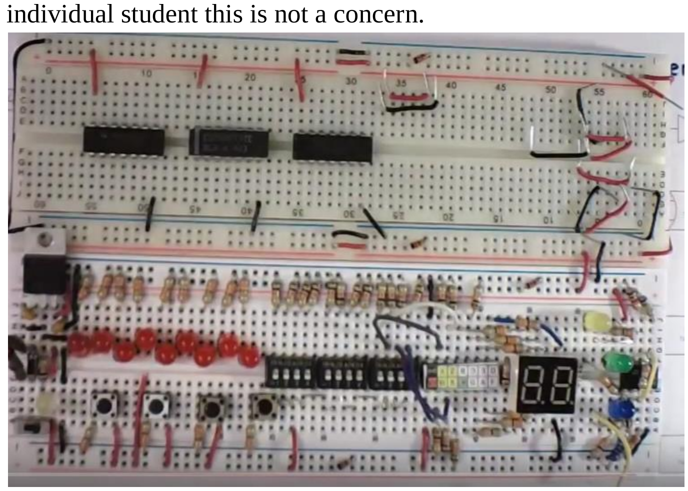

Figure 2: Standard Logic Design kit

The other remote lab experiments in the SARL platform relate directly to real life scenarios. For example, there is a traffic light experiment [9]. The student will use a python program to direct traffic. The traffic lab resembles real life, but does not incorporate any direct application to electrical, computer engineering, or computer science. The color matching lab relates directly to the interests of the logic design class and is designed to keep students engaged.

This experiment not only challenges the student with a fun game, but it also gives them a rudimentary idea of how computers and screens generate color. The current design of the lab is meant to be an introductory lab to the Logic Design course because it teaches an important engineering concept while also introducing the course material and lab etiquette. Other projects that develop online or remote labs such as PHET[10] simulator, GO-LAB[11], and VISIR[12] are similar to the remote labs at FAU, but differ in some respects. The remote labs at FAU are adapted to be a graded part of the curriculum.

IV. DESIGN

This lab was conceived to help students better understand color theory of the additive RGB color model. It is commonly thought that the painting color wheel is how all colors are made, but that is not the case from a technological standpoint. Every color can be created from the RGB color model and can have a different intensity to make a total of 16,777,216 colors when counting the intensity of each color from 0 to 255[13]. This is what the PHP random number generation code for the user interface is based off of except there is only eight basic color combinations that can be generated. Each color combination that can be generated is denoted by a six-digit hex number that consists of the intensity of red, green, and blue. This is what is used in CSS and HTML programs to add color to web pages.

Table 1. RGB Colors codification [13]

Color	Red	Green	Blue
Black	0	0	0
Red	255	0	0
Green	0	255	0
Blue	0	0	255
Cyan	0	255	255
Magenta	255	0	255
Yellow	255	255	0
White	255	255	255

The design of this lab is based on the architecture of other remote lab experiments that have been developed for the FAU Logic Design class. The experiment follows the basic structure where the student interacts with the experiment connected to a Raspberry Pi on camera with the use of either a standard logic design breadboard or the user interface directly (see figure 3). The hardware of the remote lab is not very complicated. The idea is to randomly generate a color combination from the three LEDs and let the user match that color combination. The best way to do this in a remote lab set up is to use a Raspberry Pi to light certain LED's based on a python random number generation program. The PHP program that is used for the user interface has a similar structure to generate the eight color combinations on screen. There is a single seven segment display on the remotely controlled lab in order to give the user a hint by displaying the number combination of the randomly generated color. The color combinations are displayed in table 2.

Table 2. Decimal and binary representation

Combination Number	Red	Green	Blue
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1

The user will have to match the color combinations that are displayed and if the user is inputting their color matches from the breadboard, there will be a set of uncovered LEDs and a set of LEDs that are covered and diffuse light. Both sets will be controlled by the same switches.

V. IMPLEMENTATION

A. *Networking configuration*

The color-matching remote lab will be included as one of several interactive remote labs that will be implemented by the Logic Design class in SARL. Students that log into the system and complete experiments will have their progress tracked and monitored using the xAPI module [8]. The Raspberry Pi is connected to internet and makes the Color-Matching experiment available through the SARL interface. The network of experiments can be distributed around the world and each experiment expose their interface and controls as service through the use of REST API.

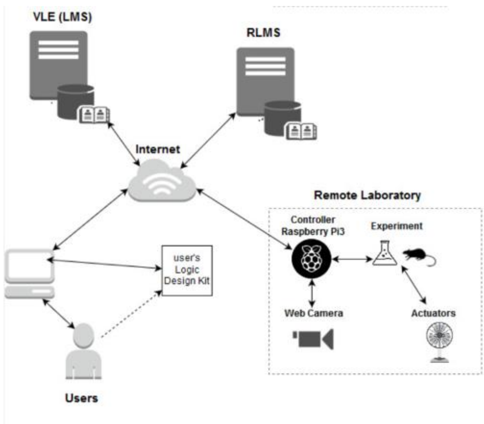

Figure 3 shows the proposed architecture of distributed remote experiments.

The Remote Lab Management System (RLMS) is the server-side portion of the architecture. The RLMS is run through a server that uses a Linux OS using its Apache HTTP (Apache2) web app server, which will connect to different functions, such as wed by the user. In addition, the server will call the domain of the website using the given URL.

B. Hardware implementation

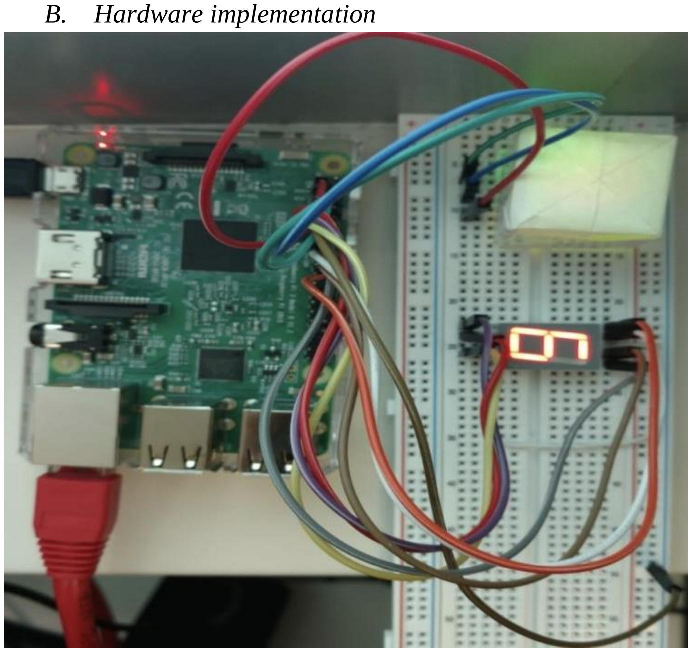

Figure 4: The remote lab is connected to the Raspberry Pi to ensure that the randomly generated colors will be displayed on the breadboard.

The remote lab itself is comprised of a breadboard with the layout implemented above. The wires are connected to the seven-segment display using a Raspberry Pi. Three other wires were connected to the corresponding LEDs on the breadboard. The red, green, and blue LED lights were connected to GPIO output 3, 5, and 7 pins respectively. The LEDs also used 1k ohm resistors on the breadboards in order to balance current flow. The remote lab uses the Raspberry Pi to also connect to the Internet and the server. Additionally, the LEDs are covered by a color diffuser, made with a piece of paper and some tape (not shown in the figure). The LEDs are to be placed lower to the ground so that the light emitting from it can properly diffuse.

C. Software and Interfaces

In total, the software used throughout the development of the color-matching experiment, as well as its integration with SARL, are the Python, PHP, HTML, and Javascript languages, as well as CSS, JSON, and Jquery technologies. On the server-side, the website that will be used to deploy the remote labs will have a login session, a scheduler, a gallery-style selection of the available remote labs. These features were developed using PHP and displayed to users through HTML. The user interface of the lab was developed the same way.

Each experiment (including color-matching) requires a Raspberry Pi controller and a web application server. The server functions as a computer and runs through the Linux OS and connects the remote lab with the rest of the architecture. The Raspberry Pi uses programmed Python code in order to conduct the remote lab experiment. The numbers on the seven-segment display represent different colors that are to be matched by the user. The program written within the Raspberry Pi allows the remote lab to simultaneously display the random color of light with the corresponding number on the seven-segment display. The PHP function then calls to execute python scripts to control the GPIO pins on the controller. Another set of functions is required (called from lab UI).

The interface provides option to generate a random color or to assign a specific color, it is sent to the lab experiment and presented using the LEDs. This combination of colors with the help of the paper diffuser, displays the color live for the user through the webcam. The remote labs, including the color-matching experiment, will have e-learning capabilities that allow the SARL system to adapt to individual student performance [15]. The interface will have the display of the live feed from the video camera, as well as python code that is used for the program. The student will be able to run the code in order to randomly generate the colors.

D. Integration with SARL

The experiment implemented is integrated to the SARL architecture through the use of xAPI[8]. This technology allows the experiment to report information about the user interactions to the Learner Record Store (LRS). This information is structured in form of triplets (actor, verb, object).
The LRS is a centralized repository of information that can be accessed by the VLE [15]. Information such as: the number of attempts made by the users to match the color on their lab kits, time expended, as well as the details about the user session and state of the remote lab experiment are capture and stored in the LRS.

VI. FUTURE WORKS AND CONCLUSION

This remote lab is unique to the current SARL platform because of the computer science application behind the concept of the experiment. The new Logic Design curriculum is meant to engage students and make them think critically about that they do in the course, as all engineering labs are. The concept of the additive color wheel is something fundamental that all engineering majors should understand. Instead of an experiment where the student uses logic gates to blink a couple of red LEDs, the student can create eight colors and learn the significance of them.

This is the first paper written about the simple introductory remote lab color matching game. This simple remote lab concept can be greatly expanded upon in the future. The point of the SARL is to update the way Logic Design labs are performed and graded. Right now, the remote lab for the color matching game does not have a graded component. In the future this remote lab can be developed to replace an experiment in the lab curriculum and be graded. This remote lab can be adapted into a counter, a number conversion lab, or a more visual representation of a state machine. Essentially, every lecture concept that can be demonstrated in a lab component can be adapted for this experiment. This will provide students with more diverse lab experiments and will lessen the probability of cheating if students get the individual which lab they would like to work on. When every student is working in the same lab, they can copy each other's breadboards. By creating more labs for students, they will have a harder time copying each other.

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