Lab-as-a-Service (LaaS): A Middleware Approach for Internet-Accessible Laboratories

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***Abstract*— [Work in Progress] The proliferation of cloud computing and web-based technologies have made it possible for universities to expand their academic networks reaching a wider range of students. In an effort to expand offered services while reducing costs, universities began exploring the use of distributed software platforms and middleware infrastructures to make laboratories accessible over the Internet. However, there are major challenges in the way these platforms enable students to effectively interact with a remote laboratory environment. In this paper, we introduce a remotely-controlled middleware infrastructure called Lab-as-a-Service (LaaS) that is based on cloud computing and service-oriented architecture (SOA) concepts. LaaS aims at providing educators with the necessary tools to deploy course lab components over the Internet more efficiently while enabling students to productively complete lab material remotely. Throughout the paper, we discuss the overall architecture of LaaS, use cases and implementation details. We further use our LaaS framework to provide insights on improving the remote laboratory experience and interactive online learning models.**

Keywords*— E-Learning, Computer Aided Instruction, Raspberry Pi, Arduino, Prototyping, Massive open online course

I. Introduction

For a number of years, traditional learning meant that the acquisition of knowledge and learning would be confined to fixed locations (i.e. classrooms). In this form of learning, teaching mainstream involved one-way learning such that instructors spend majority of their time lecturing or delivering course materials. However, this form of learning is gradually and constantly changing. Thanks to advancements in client- and server side technologies that now make it possible to create rich internet applications (RIAs) powerful enough not only to ensure the successful delivery of courses online but also provide capabilities to control devices in a remote manner.

With the use of technologies (e.g. JavaScript, AJAX, AngularJS, PHP, Python, among many others) it is now possible for instructors who use learning management systems (LMSs) to extend the knowledge acquisition form across multiple locations and not through a fixed environment. Although the number of online courses is rapidly increasing, the proliferation of online learning faces many challenges that must be taken into consideration to ensure the successful delivery of all types of courses including those that offer lab components.

Many courses often incorporate a lab component for students to conduct experimentation and gain some practical, hands-on experience where they can apply theoretical ideas into practice. Offering the theoretical portion of such courses can be achieved via online learning platforms where instructors post course materials (e.g. lectures, multimedia content, articles, among others). However, the challenge of offering the lab component portion of such courses in a remote manner remains a major problem that requires solving. This prompted us to explore the use of existing state-of-art technologies that can potentially solve existing challenges.

Advancements in areas such as Cyber Physical Systems (CPS) and Internet of Things (IoT) provide technologies and protocols that can offer a solution to this problem. For example, in the IoT paradigm, it is possible to communicate with devices remotely to collect data or send instructions. A CPS can also enable machines to communicate with each other with minimal human intervention focusing primarily on the interaction of computational and physical entities.

To overcome many of the existing limitations associated with offering online courses that have a lab component, our paper introduces a new framework called Lab-as-a-Service (LaaS) that takes advantage of cloud computing and service-oriented concepts to build IoT- and CPS- based systems for enabling students to remotely conduct experimentations or labs from a distance. We believe that our LaaS framework will help advance the expansion of offering online courses that have a lab component and in improving the online learning experience.

This paper is organized as follows. Section II discusses some of the related work in the area of online learning. Section III introduces our LaaS framework for improving the online learning experience. Section IV discusses some of the characteristics and challenges associated in designing a remote experimentation framework. Finally, conclusion and future work are discussed in Section V.

II. Related Work

A. Massive Open Online Courses (MOOCs)

A massive open online course (MOOC) is a tuition-free course taught over the web to a large number of students [1, 2]. Many leading universities around the world now offer students MOOCs such as MIT, Harvard University, University of California Berkeley, among many others. Many MOOCs have been developed within international co-operative partnerships such as edX [4], Coursera [5], Udacity [6], P2P University [7], among others. While many of these courses have proven to be

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successful given the high attribution rates, nearly all of the courses offered online do not have an experimentation component where students are able to conduct lab experiments.

Statistically, science and engineering courses represent a low percentage of MOOCs offered online. For example, chemistry MOOCs represent less than 3% of the approximately 450 courses offered through various online learning platforms [8]. This can be attributed to inaccessibility of conducting hands-on laboratory experiments in a remote manner where students are able to conduct experimentations. Some research efforts have been some possible solutions for enabling students to use online learning models such as PhET by UC Boulder [9], Molecular Workbench by the Concord Consortium [10], MERLOT Community Portals [11], among others. Although many of these platforms provide alternatives to some of the laboratory activities in science courses, there has been no alternative for actual lab environments.

B. *Remote Lab Platforms*

Over the past few years, there have been a number of remote laboratories that have received widespread acceptance among academic institutions. In [12], the authors present a learning-by-doing methodology in the area of industrial engineering. Another remote laboratory called WebLabs that incorporates web technologies to remotely conduct a very limited set of focused experiments mainly related to remote robotic control [13]. A number of similar approaches have been also proposed in literature by multiple researchers [11, 14-16]. Unfortunately, these efforts have either focused on particular discipline or utilized very primitive use of web technologies with respect to the large variety of areas that are covered by MOOCs.

The authors in [17] performed a comparative study at the Department of Mechanical and Manufacturing Engineering at the University of Melbourne randomly allocating a cohort of third-year students to one of three course modes. In a separate efforts, the authors in [18, 19] utilize a service-oriented approach for remote operation of laboratories. However, these approaches focused on a limited set of experiments and require setup that can be costly.

III. Lab-as-a-Service (LaaS) Architecture

The aim of our approach is to design a framework that increases the productivity and level of students' interaction when executing remote experiments. Through this framework, which we call Lab-as-a-Service (LaaS), students can remotely execute labs designed by instructors. LaaS incorporates a middleware approach in which it can be used universally across a wide range of experimentation types. Through the experimentation process, students can observe results via video or an interactive graphical user interface (GUI). Using LaaS, teachers can control the sequence, state, dependency and behavior of the lab processing units (LPUs). This provides students with the ability to, for example, repeat certain lab components until correct results are observed.

The LaaS framework is a CPS which can be used to control and modify the objects in a physical manner. To illustrate this, consider, for example, a microscope that can be remotely controlled via a web browser. LaaS can then be used as a platform that provides hardware and software accessibility for telemicroscopy clients (e.g. students) to control this microscope in a remote manner. In addition, LaaS continuously transfers microscopic images via the Internet for telemicroscopy clients. A high level architecture of our proposed framework is shown in Figure 1.

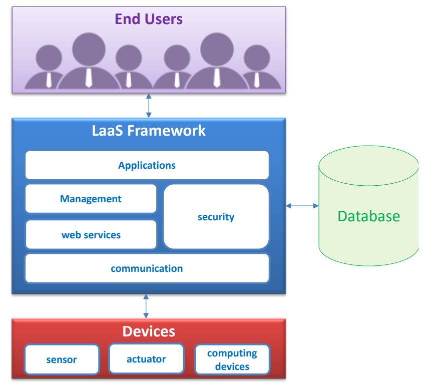

Figure 1: LaaS Architecture

Figure 1 presents a high-level overview of the LaaS Framework. In this framework, students use their computing devices to perform a set of tasks including: (1) access lab resources, (2) run labs or experiments, (3) populate lab reports or results, (4) submit documentation and (5) connect end-user computing devices. On the other hand, instructors use LaaS to perform a series of tasks including: (1) retrieve lab results, (2) grade lab reports, (3) run analytics on student lab results or data, (4) monitor student performance in real-time, (5) create lab modules, (6) create rubrics, (7) send notifications (via emails) and (8) manage and administer lab material online.

The LaaS server is responsible for managing requests and responses between students and virtual lab environments. Through LaaS, instructors are able to assess the students' understanding in real-time during a lab session. In this manner, instructors can devise any instructional interventions based on student needs as they surface. Therefore, LaaS helps in shifting passive lab environments into active ones and create a lab environment that adapts to a wider range of students accessing the system across many locations worldwide.

The LaaS framework consists of multiple components that reside on distributed system architecture. Instructors or lab supervisors access the LaaS framework using a LaaSControl (LC) component which enables them to administer and manage lab material. In particular, the CM enables instructors or lab supervisors to create lab quizzes, publish lab material, push quizzes into student sessions, among other features. A monitoring scheme called LaaSMonitor that is part of the Management component communicates with the database and continuously updates the instructors' LC interface in real-time.

A. *Operating Scenarios*

1) *Sensor Data and SQLite*

In this scenario, instructors setup a lab that uses Raspberry Pi (RPi) to connect to a temperature and humidity sensor

(DHT11) [21]. The lab requirement is that students must be able to read sensor data and store it into a SQLite database for further processing. In addition, students are asked to create a graphical user interface (GUI) that displays this temperature and humidity readings, in real time. An illustration exhibiting the relationship between the operating scenario and the LaaS framework is shown in Figure 2.

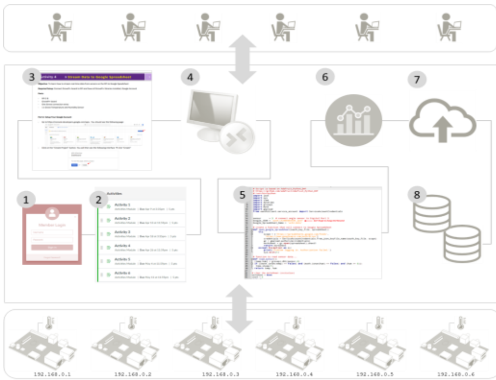

Figure 2: Utilizing LaaS to Conduct Lab Experiment

As part of this experiment, students were instructed to write a program in the Python language which enables them to issue read commands to a digital output port in the GrovePi (i.e. D4) and display results on the screen in real-time. If the sensor is connected properly, they will see the results populating on the screen prompting them to move to the next step of the experimentation. Following the communication with the sensor and collecting data, students begin developing a graphical user interface using some cloud platform (Step 6). Then, students upload their code and screenshots of their GUI results via a cloud component in LaaS (Step 7) which is then stored into a repository for instructors to download and evaluate, if necessary (Step 8). Figure 3 demonstrates sample results of students conducting this activity remotely.

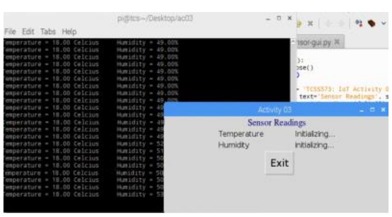

Figure 3: Sample Output for a Remote Lab Executed

2) Dashboard and Real-Time Analytics

In this lab activity, students were asked to develop a Python application such that it reads streams of sensor data and trigger a buzzer if a certain sensor threshold is reached. In particular, an ultrasonic ranger sensor from Seeedstudio [22] is used to determine the distance when an object is approaching the sensor. Figure 4 presents a web-based interface developed using Google Charts (i.e. gauges) where a program is constantly communicating with devices in a remote manner.

B. Importance and Benefits of LaaS as an Edutional Tool

While it is becoming ordinary and trivial to equip hardware prototyping platforms such as Raspberry Pi with sensors for detecting surrounding conditions (e.g. temperature, movement, etc.), deploying them on a large scale as an educational tool for conducting experiments remotely can be quite costly. For example, the kits utilized in our experiments included (a) a starter kit for Raspberry Pi 3 from CanaKit [24] and (b) a GrovePi+ Starter kit for Raspberry Pi [23]. Costs associated with the purchasing of the two kits are shown in Table 1.

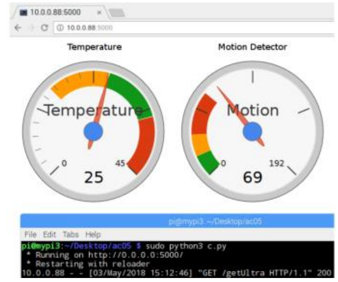

Figure 4: Google Charts Real-Time Analytics

Table 1: Cost Summary for IoT Kits Used in LaaS (June 2018)

Kit	Cost (US Dollars)
Raspberry Pi 3 Ultimate Starter Kit - 32 GB Edition	$89.95
GrovePi+ Starter Kit for Raspberry Pi	$89.99
Total (single unit from each kit)	$179.94
Total (15 units from each kit)	$2699.10
Total (40 units from each kit)	$7197.6

To illustrate the usefulness of LaaS in terms of reducing costs, Table 1 shows the total costs without taking into consideration other cost factors such as taxes and shipping which need to be factored into purchasing such equipment. For a small class of 15 students, it might be manageable to purchase such equipment. However, for a class that requires a lab component to be offered online with 100 students, it becomes extremely costly to purchase a kit for each student (total $17,994). Hence, there needs to be a framework that can optimize the number of kits while maximizing the throughput in terms of end users or students who can utilize them.

IV. Discussion and Lessons Learned

As part evaluating the effectiveness of the presented LaaS middleware, students in a graduate Internet of Things (IoT) course were asked to remotely access Raspberry Pi with the GrovePi+ shield attached to conduct a number of labs. Through LaaS, the hardware prototyping platforms were configured to generate emails to assigned students with the IP address to enable the remote connectivity to these devices. A total of 6 labs were conducted and there were 36 participating students.

Topics of the labs included collecting data via temperature and humidity sensors, motion detection, light sensing, sound sensing, controlling state of lights, among other topics. In addition, students were asked to create high level cloud-based analytics view of the data being examined or the status of the devices. Figure 5 presents screenshot examples of a home security automation student's project that integrates advanced Alexa Skills Kit and IBM Bluemix IoT Platform.

Figure 6 shows another frontend graphical user interface of a students' project that focused on the creation of a smart clock system that can be used to control lights in a home. Through

Table 2. Student Feedback from an IoT Graduate Course that Utilized Remote Hardware to Perform Lab Components

Survey Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The use of prototyping kits and the ability to execute remote operations has helped me to perform beyond basic course requirements.	83%	13%	4%	0%	0%
I recommend the use of prototyping platforms and using remote control operations via a middleware framework to be used in other computer science courses.	83%	10%	7%	0%	0%
In-class activities or exercises, such as programming, working with Node-RED, IBM Watson Cloud environment, sensor components and the ability to conduct some experiments in a remote manner has motivated me to understand other disciplines.	80%	16%	4%	0%	0%

this interface, an end-user can control the color of the clock and lights within a room. The application utilizes RESTful web services to connect via the web to collect additional information such as weather to further complement the sensing capability of the hardware module.

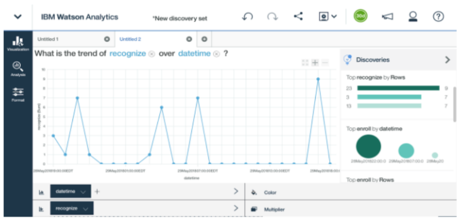

Figure 5: IBM Bluemix IoT Platform for Student Project

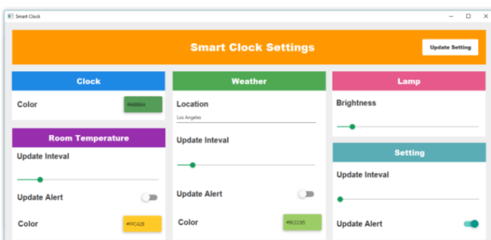

Figure 6: An Example Prototype of a Smart IoT Clock

To further demonstrate the effectiveness of the students' learning experience using the LaaS framework and their ability to remotely use hardware prototyping platforms in building IoT applications, students in the graduate IoT course offered at a North American public university [25] were invited to participate in an end-of-term survey. Thirty six students participated in this survey. The survey was presented to students after the completion of the course requirements and results of this survey are shown in Table 2.

Results from the survey show that 83% of students strongly agree that the use of hardware prototyping platforms has helped them perform beyond the course requirements. This is partially attributed to the fact that students were able to control IoT devices in a remote manner via a framework such as LaaS which has made it convenient for students to operate in groups and work collectively via the Internet to deliver course labs and projects on time. In addition, 93% of the students that participated in this post-term survey either strongly agree or agree recommend the use of hardware prototyping platforms such as RPi with remote control capabilities via a framework such as LaaS to be used in other computer science courses. Results from this survey are significant in the sense that they reflect the students' futuristic goals and how successful they were in conducting experiments or labs remotely via a middleware such as LaaS.

One key challenge that we encountered during the execution of the labs is the ability for students to verify their controllability of devices such as LEDs remotely. For example, a student who wishes to turn on the LED after a particular event needs to see the actual LED turning on or off depending on a given condition. However, students do not have the LEDs or equipment physically in front of them to make decisions or to verify the behavior of their program (e.g. working properly or not). To overcome this limitation, we asked students to check the status of the LED programmatically and based on the outcome they will be able to determine the state of the light.

The LaaS framework was tested in a graduate IoT course with thirty six students. Results from our end-of-term survey demonstrate the effectiveness and usefulness of our approach. However, scaling up this system will require further testing and a larger infrastructure to accommodate more complex scenarios such as biology labs, chemistry labs, engineering labs, among others.

We believe that the current LaaS will help us identify the existing challenges in the ability for students to remotely execute labs. Nevertheless, we plan to take advantage of the current robotic machinery or machine-to-machine (M2M) equipment that are very common in manufacturing or industrial facilities where machines communicate with each other to execute a process with no human intervention. By applying these concepts and integrating them to the current LaaS framework, it is then possible to build a more sophisticated framework that is capable of enabling a larger number of students to connect to hardware modules remotely and executing commands more efficiently. In addition, we plan to install cameras in the lab facility where these hardware modules are installed such that students are able to see in real-time the execution of their labs remotely.

V. CONCLUSION

In this paper, we introduced Lab-as-a-Service (LaaS) framework for improving the online learning experience. The LaaS Framework enables students to engage more actively in courses that need hands-on components. Throughout this paper, we have demonstrated at a small scale how the LaaS framework can be used to transform a traditional learning experience to a remote learning experience that can complement existing MOOCs. This helps to promote courses that require lab facilities to also be incorporated to the online learning environment. For future work, we plan to extend the LaaS framework to take into consideration scalability and complexity of more sophisticated lab equipment that are required for courses in engineering, science, among others.

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