Mobile laboratories as an alternative to conventional remote laboratories

Abstract ***– Remote laboratories have been playing an important role on the improvement of flexibility and the extent of practical activities in teaching and learning activities in engineering and technology. However, the current remote laboratories model does not consider dynamic scenarios including collaboration, peer-to-peer labs and mobile labs. This paper presents a set of tools for creating collaborative online mobile laboratories that allow students to develop their own labs and share them with classmates and teachers. The approach used is compatible with the machine and network configurations that the target user has in schools and at home, and provides the retrieval of information for learning evaluation.***

Keywords - online labs, remote engineering, mools, mobile labs.

I. Introduction

For teaching and research in science, engineering and technology, experimentation is a core learning activity, and the reality of laboratory practices has been profoundly changed by the Information and Communication Technologies. Tools such as simulations, virtual reality and remote laboratories have been used to make classes more interactive. Even traditional labs are, most of the time, mediated by computers and other digital devices.

Faced with a significant increase in enrollment in education and research institutions in some developing countries, such as Brazil [1] , and with the need for mobility of students in some developed countries, major challenges are to overcome in order to achieve educational goals required. The challenges that we already know are those of the availability and management of conventional laboratory rooms for many learners, acquisition and maintenance of equipment as well as software updates that are constantly changing.

In this context, online labs have been used for quite some time as an alternative to traditional hands-on laboratories. Online labs are “information technology enabled environments that a learner uses to perform laboratory work over computer networks, alone or in collaboration with other participants in a distance or flipped learning context” [2]. Remote labs (also known as weblabs [3]), for example, have been used to make laboratory activities more flexible in many branches of knowledge, and in different educational stages: primary [4], secondary [5] and tertiary[6, 7].

Like other researchers who performed work on online laboratories, we had advocated for a long time for the use of remote laboratories. Even though virtual labs follow a mathematical model in order to achieve results close to nature, they are not able to handle experimental behavior in real environments. Remote labs, on the other hand, use real devices that can be manipulated by students, representing real systems more effectively.

However, in order to implement remote laboratories for teaching and learning in science and engineering, many challenges have been overcome so far and other solutions still need to be found. For instance, interoperability and management of federated remote laboratory resources are the main concern when it comes to sharing labs among different institutions [8].

As an alternative to remote laboratories, in this paper we propose the use of MOOLs (Mobile Open Online Laboratories), which have also been called Massive Open Online Laboratories in prior research. In our case, the judicious implementation of technologies enhanced learning for distance education, flipped classroom pedagogy, cloud computing, social web technologies and the advantages offered by several initiatives on open source code, miniaturized electronic equipment would democratize lab work using MOOLs and Lab@home [9] concept thus promoting access to the greatest number of learners.

Our paper presents a proof of concept and experienced concretely realized jointly with laboratories in three countries located in three continents, i.e. Brazil, in South America, Canada, in North America, and Portugal, in Europe. The paper is structured as follows: section “Experimentation in Collaborative Online Environments” introduces the different concepts surrounding online laboratories and explores online collaborative experimentation, the section “Learning Experience in Online Experimentation” presents the use of Experience API for storing learning experiences, in section “Solution Prototype” we present the architecture and each module used in this proof of concept, and section “Final Considerations” presents the outcomes of this work.

II. Experimentation in Collaborative Online Environments

Online laboratories have been frequently used as a complement to the hands-on experimentation, or in some cases, as in distance education, as an alternative to traditional laboratory activities. These technology-based resources enable students and teachers to conduct laboratory practices more flexibly and interactively, and can provide different experiences considering the many possible setups. Depending on the experiment's location and nature (how real or virtual it is), online labs are usually classified as virtual [10-12], remote or hybrid laboratories. One of the most accepted models, presented with a few variations in, as presented in the figure below.

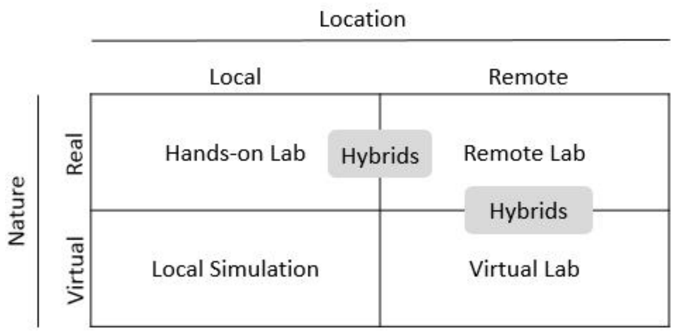

Fig. 1 Laboratories classification, adapted from [10-12]

Virtual laboratories use mathematical models to simulate the phenomena studied, using usually a digital interface based on the real equipment for input and output. These laboratories are highly flexible and scalable, but they normally disregard environmental variables and experimental error.

Remote laboratories, on the other hand, use real equipment that can be controlled through the internet. However, they are a lot more difficult to manage and scale, requiring complicated queueing and scheduling, and the creation of multiple instances of a laboratory in order to support its use in a production environment. Moreover, depending on the setup, a remote laboratory can be very specific, requiring many rules for security to prevent damage [13] and ensure that the user obtains the results expected.

Hybrid laboratories are solutions composed by different types of laboratories. Usually the approach towards hybrid labs considers only cases composed by real and virtual laboratories, as described in [12]; however, depending on the learning scenario, a remote laboratory could be manipulated using local real controls (haptic devices [14], for example), being then a hybrid lab.

The concept around mobile laboratories has been explored for quite some time now, and interpreted in different ways by researchers in education, science and engineering [15]. One of the recurring approaches, as presented by Silva, et al. [16] and Zappatore et al. [17], is associated with the traditional conception of remote experimentation, making use of mobile devices to access and manipulate labs in different locations through the internet.

On the other hand, the idea we have of mobile labs [2, 9] is more related to the device under control being mobile, and hosted by the student [18-20]. Students can create their own laboratories using low cost microcontrollers, such as Arduino, or single-board computers like Raspberry Pi. Even though the laboratories in this case are real and hands-on, the device under control needs to be connected to the internet in order to share its control, inputs and outputs among users in a collaborative scenario. In this case, these labs could be described as hybrid, since it can be remote or hands-on depending on who holds the equipment and who is controlling it.

Moreover, mobile laboratories can open a number of new possibilities for collaborative environments. Advances have been made in prior research in order to enrich collaboration in online experimentation, and solutions such as collaborative environments [21] and virtual 3D worlds [22] have been used in order to share remote laboratories. By using mobile laboratories in such scenarios, multiple groups are able to perform the same experiment at the same time, users can pause sessions and resume at any time without resetting the lab or waiting for other users.

In order to develop a common application layer for mobile laboratories, compatible with different rigs and clients, it is important to take an approach based in modules that can be reused in different applications. The solution explored by Tawfik et al. [23], known as Lab as a Service (LaaS), proposes that online laboratories be delivered as a service able to exchange and use information from different systems and services. This method relies on the development of online labs as independent component modules, in order to facilitate maintenance, reuse and interoperability.

In this sense, the Smart Device specification describes communication and interfaces between client and server, providing a set of information that can be used for providing web services to access sensors and actuators [24].

III. Learning Experience in Online Experimentation

Assessing students' learning outcome is crucial when performing laboratory activities in online environments. Tracking users' behavior on learning applications is important not only for assessment, but also for discovering learning patterns and designing better activities. Learning recording and analytics were also explored in remote labs applications, either by using social network analysis to track students experience [25] or even using learning analytics to offer students social and self-awareness through the remote experimentation process in order to achieve deep learning [26].

Considering the mobile labs scenario, where the learning experience is student-centered, the teacher needs to have proper feedback from the activity development in order to determine if the experiment had the expected outcome and if the students learned the skills necessary in that scenario. Assessment is also a problem when using labs in large courses or MOOCs, requiring considerable effort and time from teachers and tutors.

The use of Experience API (xAPI), previously known as TinCan API, enables the easy discovery of learning behavior by making possible the formalization, storage and retrieval of learning experiences [27]. The data stored can be used by teachers to track the students' progress in general subjects or in specific skills, facilitating their assessment and the evaluation of the educational object.

A learning experience in xAPI is tracked and formatted into a statement, in which an actor performed an action in an object (actor + verb + activity + additional properties) [28]. This statement is then stored in a Learning Record Store (LRS), from where it can be posteriorly retrieved and analyzed.

The LRS can provide data to other applications, such as Learning Management Systems (LMS), and also has a reporting mechanism, allowing the visualization of data from the combination of actor, verb and activity over time.

III. SOLUTION PROTOTYPE

The solution described in this work is composed by four main components presented in Figure 2: a Smart Device, Lab Gateway, Learning Record Store (LRS), and Lab@Home, a collaborative learning environment. The first component defines communication interfaces between lab server and lab client.

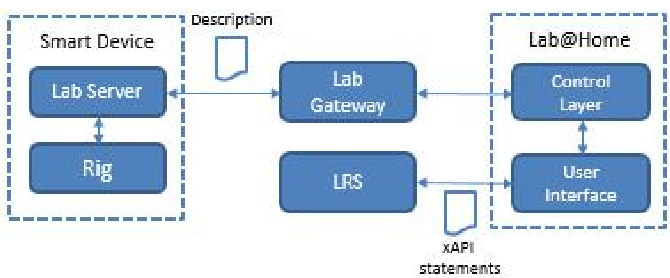

Fig. 2 Architecture used in the proof of concept

To tackle some problems related to network configuration and device discovery, a Lab Gateway is placed between the Lab@Home and the Smart Device. The Lab@Home comprises different features of a collaborative learning environment and also provides access to remote labs. Finally, students' interaction with the learning environment is stored for further analysis, which is captured by the xAPI plugin in Lab@Home and recorded at the LRS.

In this scenario, lab server is a device capable of managing a physical equipment which is the target of this solution, whereas the lab client is the application included on the user interface found in Lab@Home component. The smart device specification implies in delivering all functions and lab components in a service description file as a set of abstract services. We extended the specification to fit MOOLs behind firewall, NAT networks or other network configuration which could block access to the lab server from anywhere on the Internet.

Our approach is based on a lab server disguised of client application available only through WebSocket channels. As WebSocket provides a full-duplex communication channel over a single TCP connection, its client can act both as server and client at the same time, that is the same principle of WebRTC. However, a centralized gateway called Lab Gateway is needed to give access to these lab servers.

So, a client application will connect to the gateway and make requests as described in the description file, which includes both HTTP and WebSocket requests. We decided to take a client approach instead of using the board also as the lab server because in this scenario, where the student has the laboratory at home, users generally will not have valid IP addresses available.

We provide two implementation of smart device, one of them suitable for Arduino and compatibles and another for single board computers using Node.js, such as Raspberry Pi. Both implementation are based on socket.io protocol, which extends WebSocket features. Thus, using these codes as templates, the rig and lab server can be developed by students themselves, and then connected to the Lab Gateway through WebSocket. Analyzing electrical circuits is simple example of use, since most of the development boards enable signal generation and acquisition.

The Lab Gateway is an application responsible for forwarding the requests from the client to the lab server. It acts as a middleware translating requests, either WebSocket or HTTP requests, from the users or even from the lab server. As showed in Figure 3, the communication has to be initiated by the lab server, as it also informs the actual lab status, i.e., if it is online or offline. Besides sending the description file, the lab also establishes a WebSocket channel which will be used to exchange data coming from the stub services.

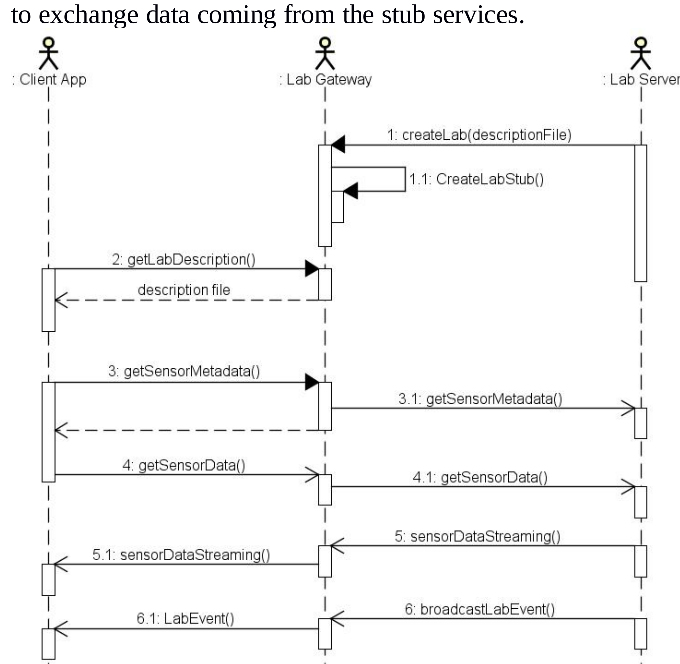

Fig. 3 Ativity Diagram

As soon as the description file is stored and parsed, the Lab Gateway creates a stub implementation of the smart device and binds HTTP or WebSocket messages coming from the users to that lab server. The Lab Gateway deliveries the lab description to the lab client as it was a smart device, even replacing addresses and paths in the service description file.

The group of users who will connect to the lab server is defined in the collaboratory, as the lab gateway shares information through the same MySQL database that Lab@Home uses. Users can receive broadcast messages originated from the lab server and use the concurrency mechanism defined by the lab server.

Lab@Home, the client application (Figure 4), was developed as a responsive web application, making it compatible with mobile devices and desktop. The user interface was in HTML5, using the front-end framework Bootstrap 3, and the JavaScript library jQuery 3. The back-end is based on Laravel 5.3, a PHP MVC framework. For the chat and the files sharing, as well as for updating users' status, it was used a Node.JS server with the Socket.IO library.

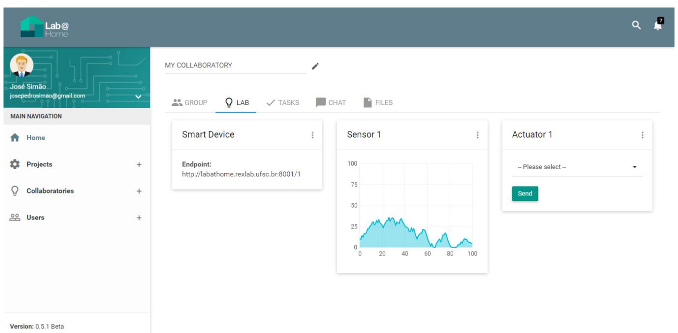

Fig. 4 An example of collaboratory proving laboratory interface

Students access and manipulate the labs, create laboratory in order to share devices and interact with other users during the experimentation process. The workspaces are created by the own students, who can also edit information and add other members.

Among the functionalities available in the collaboratories are user management (user status, adding and removing), file sharing in group and individual file repositories, chat room and tasks management (creating, assigning, completing and due to). Users can also create a videoconference room inside the collaboratory, where they can talk, share their screens and show the device under test. The videoconference tab was developed using Appear.in SDK, a video call software.

All the messages sent in the chat, files and takes from a collaboratory session are stored on the database, so that users can pause and restart a session, or retrieve data from finished collaboratories.

The collaboratories can also be created from project templates defined by teachers, with specific tasks and files. A specific interface for the laboratory can also be defined by the teacher in the project creation, so in an assignment, for example, all students in a course can have the same resources.

The actions and outcomes of collaboratories are stored in a LRS using xAPI. We consider both users and smart device as actors, storing not only users' interactions with the system and with each other, but also the messages sent by the smart device. The vocabulary used by the human actors can be generalized, and is more connected to behavior aspects (display, require, present, connect, disconnect, share, etc.), while the vocabulary used in smart device can vary depending on the experiment, being in this case specified on the description file.

We use an instance of Learning Locker (Figure 5), a PHP based LRS that receives the statements generated in the collaboratory user interface by AJAX requests. This implementation provides reporting functionalities, making possible generate graphs and export data by different combinations of actors, verbs and objects.

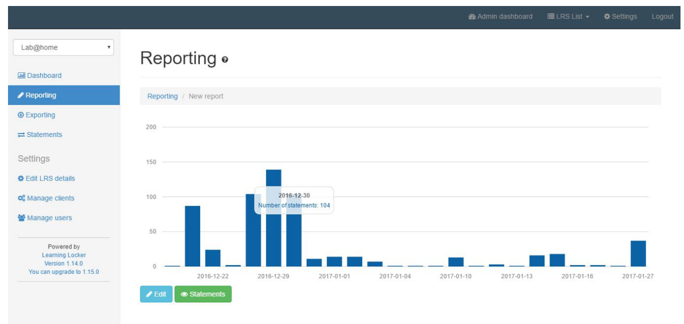

Fig. 5 Learning Record Store

IV. Final Considerations

This work addressed the creation of a collaborative environment for mobile online experimentation. The solution makes possible for students to create their own laboratories and share them in a collaborative environment. In addition, we provide software templates for widely known development boards, which enables students to use their own electronic equipment to extend lab work using MOOLs and Lab@home concept.

The model adopted in the development, using the lab gateway to connect devices without valid IP addresses to the client application, can be used in different scenarios to publish online laboratories, minimizing problems with NAT and firewalls, for example.

Regarding the use of xAPI, there is still no vocabulary specified for storing online laboratories learning experiences. Standardized this vocabulary is of extreme importance, allowing cooperation and comparison of results among different studies. In this sense, as a future work, it would be important to define verbs and activities for using xAPI with online laboratories.

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REFERENCES

[1] UNESCO Institute for Statistics, "Brazil - Education and Literacy". Available at <http://uis.unesco.org/country/br>, accessed in 12/13/2016

[2] H. Saliah-Hassane and A. Reuzeau, "Mobile open online laboratories: A way towards connectionist massive online laboratories with x-API (c-MOOLs)," in 2014 IEEE Frontiers in Education Conference (FIE) Proceedings, 2014, pp. 1-7.

[3] G. Martínez-Pieper, I. Angulo, and J. García-Zubia, "Weblab - Microscope: A remote laboratory for experimenting with digital microscope," in 2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV), 2016, pp. 159-162.

[4] C. P. Antonio, J. P. C. Lima, J. B. M. Alves, J. B. Silva, and J. P. S. Simão, "Merging a Remote Microscope and Virtual Worlds: Teaching Kingdom Plantae on Basic Education," International Journal of Online Engineering (iJOE), vol. 12, no. 4, p. 3, 2016.

[5] J. P. S. Simão et al., "A remote lab for teaching mechanics," in 2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV), 2016, pp. 176-182.

[6] J. García-Zubía and G. R. Alves, Eds. Using Remote Labs in Education: Two Little Ducks in Remote Experimentation, 1 ed. Bilbao: University of Deusto, 2011.

[7] M. A. Marques et al., "How Remote Labs Impact on Course Outcomes: Various Practices Using VISIR," IEEE Transactions on Education, vol. 57, no. 3, pp. 151-159, 2014.

[8] P. Orduña, "Transitive and Scalable Federation Model for Remote Laboratories," PhD, Universidad de Deusto, Programa de Doctorado en Sistemas de Informacion, 2013.

[9] M. S. Hamadou Saliah-Hassane, Willie K. Ofosu, Willie K. Ofosu, Hassane Alzouma Mayaki, Mamane Moustapha Dodo Amadou, "Lab@Home: Remote Laboratory Evolution in the Cloud Computing Era," presented at the 2011 ASEE Annual Conference & Exposition, Vancouver, 2011.

[10]M. Auer, A. Pester, D. Ursutiu, and C. Samoila, "Distributed virtual and remote labs in engineering," in IEEE International Conference on Industrial Technology, 2003, 2003, vol. 2, pp. 1208-1213 Vol.2.

[11]D. G. Zutin, M. E. Auer, C. Maier, and M. Niederstätter, "Lab2go: A repository to locate educational online laboratories," in IEEE EDUCON 2010 Conference, 2010, pp. 1741-1746.

[12]L. Rodriguez-Gil, J. Garcia-Zubia, P. Orduna, and D. Lopez-de-Ipina, "Towards new multiplatform hybrid online laboratory models," IEEE Transactions on Learning Technologies, vol. PP, no. 99, pp. 1-1, 2016.

[13]M. A. Bochicchio and A. Longo, "Hands-On Remote Labs: Collaborative Web Laboratories as a Case Study for IT Engineering Classes," IEEE Transactions on Learning Technologies, vol. 2, no. 4, pp. 320-330, 2009.

[14]M. T. Restivo, A. M. Lopes, L. d. S. Machado, and R. M. d. Moraes, "Adding tactile information to remote & virtual labs," in 2011 IEEE Global Engineering Education Conference (EDUCON), 2011, pp. 1120-1124.

[15]R. J. Costa and G. R. Alves, "REMOTE AND MOBILE EXPERIMENTATION: PUSHING THE BOUNDARIES OF AN UBIQUITOUS LEARNING PLACE," IFAC Proceedings Volumes, vol. 39, no. 4, pp. 314-320, // 2006.

[16]J. B. d. Silva, W. Rochadel, J. P. S. Simão, and A. V. d. S. Fidalgo, "Adaptation Model of Mobile Remote Experimentation for Elementary Schools," IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, vol. 9, no. 1, pp. 28-32, 2014.

[17]M. Zappatore, A. Longo, and M. A. Bochicchio, "Enabling MOOL in acoustics by mobile crowd-sensing paradigm," in 2016 IEEE Global Engineering Education Conference (EDUCON), 2016, pp. 733-740.

[18]D. A. H. Samuelsen and O. H. Graven, "An affordable pocket lab for a module in analogue electronics," in 2016 International Conference on Interactive Mobile Communication, Technologies and Learning (IMCL), 2016, pp. 88-92.

[19]M. L. García, G. C. Fernandez, E. S. Ruiz, A. P. Martín, and M. C. Gil, "Rethinking remote laboratories: Widgets and smart devices," in 2013 IEEE Frontiers in Education Conference (FIE), 2013, pp. 782-788.

[20]D. May, C. Terkowsky, T. Haertel, and C. Pleul, "The laboratory in your hand Making remote laboratories accesible through mobile devices," in 2013 IEEE Global Engineering Education Conference (EDUCON), 2013, pp. 335-344.

[21]M. A. Bochicchio, A. Longo, L. Vaira, and M. Zappatore, "Fostering online scientific experimentations in universities and high schools: The EDOC project," in 2015 3rd Experiment International Conference (exp.at'15), 2015, pp. 337-342.

[22]A. Caroline Porto, S. José Pedro Schardosim, A. João Bosco da Mota, S. Juarez Bento da, and S. Aline Coelho dos, "Using 3D Virtual Worlds Integrated to Remote Experimentation in Sciences Teaching," in Gamification-Based E-Learning Strategies for Computer Programming EducationHershey, PA, USA: IGI Global, 2017, pp. 195-220.

[23]C. S. Mohamed Tawfik, Denis Gillet, David Lowe, Hamadou Saliah-Hassane, Elio Sancristobal, Manuel Castro, "Laboratory as a Service (LaaS): a Novel Paradigm for Developing and Implementing Modular Remote Laboratories," International Journal of Online Engineering (iJOE), vol. 10, no. 4, p. 9, 2014.

[24]C. Salzmann, S. Govaerts, W. Halimi, and D. Gillet, "The Smart Device Specification for Remote Labs," International Journal of Online Engineering (iJOE), vol. 11, no. 4, pp. 9-29, 2015.

[25]P. Orduña, A. Almeida, D. López-de-Ipiña, and J. Garcia-Zubia, "Learning Analytics on federated remote laboratories: Tips and techniques," in 2014 IEEE Global Engineering Education Conference (EDUCON), 2014, pp. 299-305.

[26]R. Venant, P. Vidal, and J. Broisin, "Learning Analytics for Learner Awareness in Remote Laboratories Dedicated to Computer Education," presented at the Workshop on Learning Analytics for Learners in 6th International Conference on Learning Analytics and Knowledge (LAK 2016), Edinburgh, United Kingdom, 2016.

[27]W. M. A. F. W. Hamzah, N. H. Ali, M. Y. M. Saman, M. H. Yusoff, and A. Yacob, "The use of Tin Can API for web usage mining in E-learning applications on the social network," in 2015 IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE), 2015, pp. 113-118.

[28]Advanced Distributed Learning. ADL. Experience API: Advanced Distributed Learning (ADL) Co-Laboratories. Available in <https://github.com/adlnet/xAPI-Spec/blob/master/xAPI-About.md#introduction-/partone>, acessed in 27/01/2017.