The Remote Laboratory Management System (RLMS) Pattern

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Online laboratories have become an alternative for the lack of hands on experiences in online education and a requirement for engineering education. This systems have problems of accessibility, reliability, adaptability, scalability, security, among others. Additionally current online laboratory systems implementations do not follow any common pattern or reference architecture for their design, for those reasons is important to define general models and architectures that can be used as templates for the implementation of these laboratory systems. We present a pattern for the Remote Laboratory Management System (RLMS) and its integration with an Online Laboratory System.

Categories and Subject Descriptors: H.1.2 [**Models and Principles**]: User/Machine Systems—*Human Information Processing*; I.5.1 [**Pattern Recognition**]: Models—*Neural Nets*

General Terms: Design

Additional Key Words and Phrases: Patterns, Remote Laboratory Management System, Online Laboratories

ACM Reference Format:

Zapata Rivera, L. F. and Larrondo Petrie, M. 2018. The Remote Laboratory Management System (RLMS) Pattern. jn 2, 3, Article 1 (May 2010), 9 pages.

1. INTRODUCTION

Online laboratory systems have been evolving over the years thanks to the advances in technologies such as internet, software interfaces and hardware integration. These systems are now being implemented by companies and educational institutions. Online Education has problems to provide hands on experience to their students. Online laboratories have become an alternative for them. This poses a challenge for online laboratory providers to offer high quality services in terms of accessibility, reliability, adaptability, scalability, security, privacy, among others. Most of the current developments on online laboratories were not implemented using software engineering standards. In this paper we present the Remote Laboratory Management System (RLMS) pattern, which is one of the main components of the online laboratories software architecture.

Software and hardware architectures of online laboratories vary according with the type of laboratory implementation. The taxonomy of online laboratories includes: virtual and remote laboratories and hybrid configurations Zutin et al. [2010]. In the educational context, online laboratories are commonly used in topics such as: control systems, digital electronics, physics, medicine, biology, among others. Remote laboratories, particularly, can be classified as synchronous or asynchronous. Synchronous when the interaction occurs in real time and asynchronous when the user sends commands and the lab executes them in batch mode Agrawal and Srivastava [2007]. One of the problems identified in online laboratory architectures is the lack of common patterns for its design. General models that define the common interactions will ease the design and implementation of these systems.

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The Smart Adaptive Remote Laboratories (SARL) Zapata-Rivera and Larrondo-Petrie [2016] provides to **Users** individualized experiences of the laboratory experiments. The student experience is created in form of Smart Laboratory-based Learning Objects (SLLO) defined based on the previous definition of the Laboratory-based Learning Object (LLO) Duan et al. [2005]. The SLLO includes lab activities, assessment information, student information, and information about the access to the remote laboratory experiments. These learning objects are managed by the Remote Laboratory Management System (RLMS). In the SARL architecture, the **RLMS** can be integrated to a Virtual Learning Environment (VLE), that could be a Content Management System (CMS), Learning Management System (**LMS**), Actionable Data Book (**ADB**) or any other type of VLE. The VLE system will share the user information and roles in the system. This integration is possible through the use of standard technologies such as Learning Tools Interoperability (**LTI**) or through the implementation of web services, for example RESTful web services. LTI module provides session information to the session manager and allows the correct visualization of user laboratory interface inside the VLE. The experience API (**xAPI**) module is responsible to inform about the user interaction in the system and to report information to the **Learning Analytics** module. **Reliability** module detects failures and report them to the lab manager. The **Smart Adapter** retrieves the laboratory activities and assessment content from the VLE, and connect them with one or more **Online Laboratory Stations** to create SLLOs. **Security and Privacy** module is connected with all the other modules providing services such as: identity validation, encryption, detection of anomalies in the system (attacks, malicious code insertion, etc).

The rest of the paper is organized as follows: Section 2 presents the pattern proposed for the RLMS, conclusions and future work are presented in section 3. We use the template of Buschmann et al. [1996] to present our pattern. Our audience includes online laboratory systems developers and users.

Figure 1 presents the packages diagram of the SARL system that includes the RLMS as one of its modules.

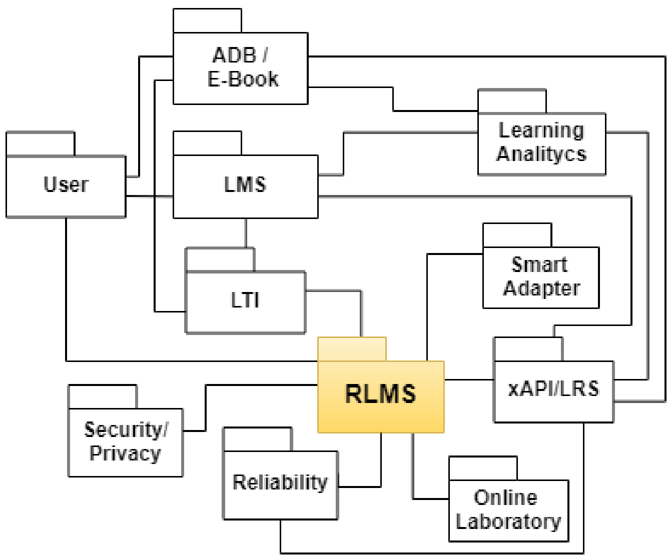

Fig. 1. RLMS as module of the SARL System

2. REMOTE LABORATORY MANAGEMENT SYSTEM (RLMS) PATTERN

2.1 AKA

Remote Laboratory Management System, Remote Laboratory Broker, Remote Laboratory System.

2.2 **Intent**

A RLMS is a system that centralizes access control to laboratory experiments, additionally provides functions for the management of laboratory experiments, such as: authentication, authorization, scheduling, lab resources management and authoring tools for the management of the laboratory experiments activities.

2.3 **Example**

Our educational institution offers to students a set of laboratory experiments, but sometimes the students need to have access to a different type of experiment that is not available in the school. We found another institution that has an online experiment available in their laboratory facility. We need a RLMS to integrate and customize the laboratory experiments. Having this infrastructure the institution can give access to the remote students and manage the schedule of use the lab experiment giving them specific slots of time in which this lab will be available for external access. The RLMS will help also giving the reports to the other institution about the users and results of the laboratory activities.

2.4 **Context**

The concept of RLMS has been developed since the last decade. Harward et al. [2008] define a centralized remote laboratory service broker that integrates distributed experiments and Bin et al. [2011] define a four layer architecture system that offered services such as: remote monitoring and control software the routine laboratory management, online experiment booking, remote visual experiment, instruction and evaluation.

Educational and industrial distributed laboratory facilities make use of RLMSs for the management of their remote laboratories and for the integration of external laboratory resources to provide an online laboratory environment.

2.5 **Problem**

The remote laboratory experiments are typically composed by activities, lab equipment, controllers, cameras and interfaces. These laboratories have many problems in terms of accessibility, concurrency, portability, reliability, scalability, adaptability and security.

The solution to this problem is affected by the following forces:

—***Accessibility***
Accessibility problems occur when the online laboratory system do not offer a centralized access to the laboratory experiments, making hard for the user find some specific experiment.

—***Concurrency***
The remote laboratories are systems that normally do not allow concurrent users. Due to this issue, online laboratory experiments most of the time are not available.

—***Portability***
Due the lack of standard formats for the remote laboratories, it is not possible to provide easy portability of laboratories from one RLMS to another, each implementation requires to follow the definitions of the host RLMS.

—***Reliability***
Due to the extensive use of hardware in this type of systems, it is common to have reliability problems.

—***Scalability***
When the number of users increases, it is not easy to scale these systems due to the level of cohesion between the components of the laboratory systems, affecting the quality of the service in terms of usability and performance.

—***Adaptability***
Remote laboratories are generally created to provide specific services. One lab is intended to be used to perform a specific measurement, reading or interaction. The teacher has not the ability to adapt or compose laboratories from existing online labs.

—***Security and Privacy***
Online laboratory system are commonly implemented without taking into account security and privacy aspects. This is caused in part because there are no security experts involved in the development of the projects, that can help in securing the systems.

2.6 Solution

The RLMS is composed by: the user *Authenticator*, based on Brown and Fernández [2004], that validates the user identity. The *Authorizer* based on the authorization pattern proposed by Priebe et al. [2004], that validates if the authenticated user has the credentials to access certain sections of the system, in this case specific modules according to the role in the system (Administrator, Student, Teacher). The *SessionManager*, based on the session pattern proposed by Priebe et al. [2004], is responsible of providing the environment where rights of the user are controlled, for example, while the user session is active in the system, the user can access the resources available for his role. The *SessionManager* also implements a mechanism to close the session when the user requested or when the user is inactive for a specific period of time. The *Scheduler* manages the user booked sessions with the laboratory experiments. The *ResourceManager* is a critical component that controls the availability of the laboratories stations, activities and laboratory experiemnts, this module has to be available for the *LabExperimentAuthoring* component in which the teacher creates, compose or edit laboratory experiments that are stored in the *ResourceManager* and that can later be posted as an available resource in the *LabGallery*.

2.6.1 ***Structure***. Figure 2 presents the class diagram of the RLMS pattern.

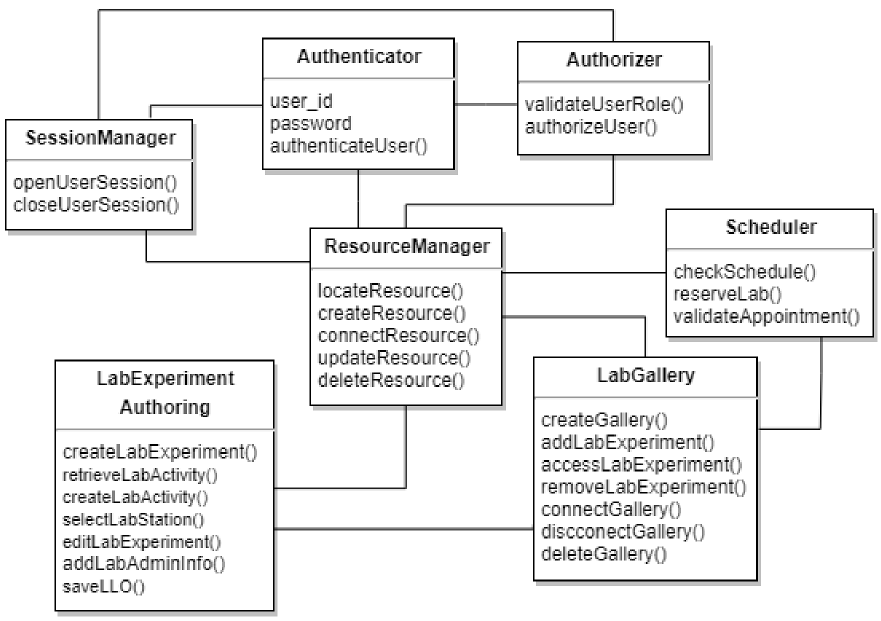

Fig. 2. RLMS Pattern

2.6.2 ***Dynamic***. We present two use cases that describe some of the dynamic aspects of the pattern. Figures 3 and 4 present the sequence diagrams of both use cases.

Use Case: Creating a laboratory experiment

Summary: A person in a role of teacher or lab administrator creating a laboratory experiment selecting a lab station(s) and attaching to it one or more laboratory activities

Actors: Person (Role teacher or lab administrator)

Precondition: The actor has been authenticated in the system with the teacher or lab administrator role

Description:
1. A user requests to create a laboratory experiment in the LabExperimentAuthoring component
2. The LabExperimentAuthoring asks to the Authorizer for access permission with the user id and role
3. If user is authorized, the user can access LabExperimentAuthoring component
4. The user starts with the first step describing the activity(s)
5. The user selects the laboratory station(s) from the available resources in the ResourceManager
6. The user finalizes the process including administrative information (topic, activity duration, class, topic, difficulty level, etc)
7. The user request to the LabExperimentAuthoring to save the laboratory experiment as a LLO
8. LabExperimentAuthoring stores the LLO in the ResourceManager the as one of the available resources

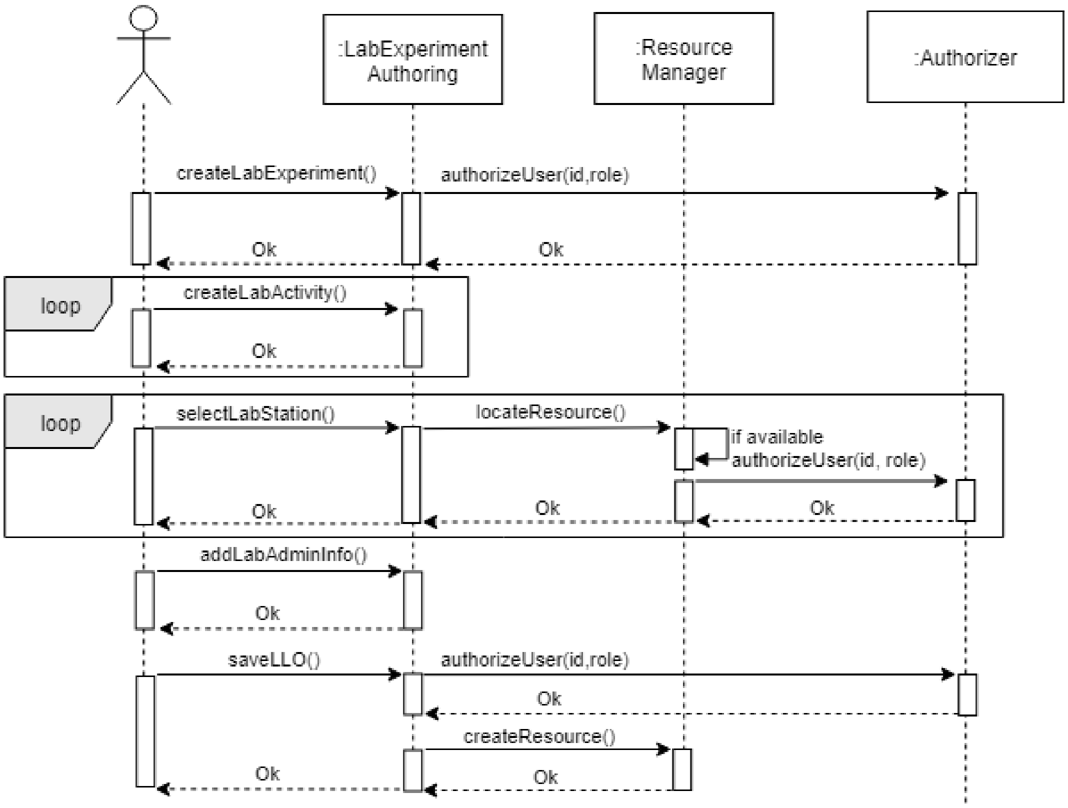

Fig. 3. Sequence diagram use case creating a laboratory experiment

Use Case:	Accessing a laboratory experiment
Summary:	A person in a role of student requests accessing a laboratory experiment that he or she has already scheduled
Actors:	Person (Role student)
Precondition:	The actor has been authenticated in the system with the student role and had an appointment scheduled
Description:	1. A user requests access to the laboratory experiment from the LabGallery 2. The LabGallery validates with the Scheduler if the user has an active appointment 3. If the appointment is scheduled, a laboratory connection request is sent to the ResourceManager 4. The ResourceManager validates with the Authorizer if the user role still has permission to access the laboratory experiment 5. The user access to the laboratory is granted

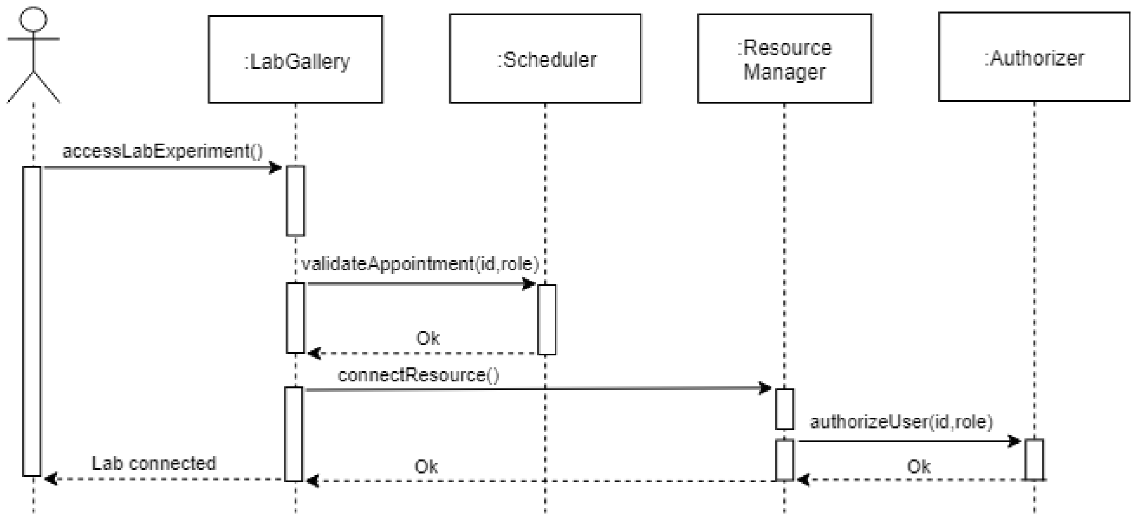

Fig. 4. Sequence diagram use case accessing a laboratory experiment

Other related use cases include: publishing a laboratory experiment in the gallery, editing an existing laboratory experiment, scheduling lab appointment, etc.

2.7 RLMS Known Uses

Online laboratory provider companies, educational institutions and international collaboration projects, have developed online laboratory systems and have implemented their particular version of the RLMS. Some examples are:

—ISA Harward et al. [2008]: The ilab Shared Architecture (ISA) is composed by three components. First is the computer that controls the experimental setup. The second component is the user interface. Finally, the service broker that acts as an RLMS linking the other two components and scheduling the access to different iLab equipment around the world.

—LiLa Lanchas et al. [2011]: Library of Labs (LiLa) is an initiative of eight European universities and three companies, which aims developing an integrated platform for remote experiments and virtual laboratories. LiLa project implements RLMS functions such as: access control and booking systems for accessing either virtual or remote laboratories.

—LabShare Lowe et al. [2009]: LabShare project from the University of Technology Sydney (UTS) has developed its online laboratory architecture, during the last decade. Their centralized system uses the RLMS to manage the access to their laboratory network to other Australian universities.

—VISIR Gustavsson et al. [2007] : Virtual Instruments Systems In Reality (VISIR) was developed by Blekinge Institute of Technology in Sweden (BTH). VISIR is focused in online laboratories specifically in areas of electrical and electronics engineering, including hybrid, virtual, and remote experiments. VISIR experiments have been integrated and replicated in different RLMSs in several countries around the world.

—WebLab-Deusto Garcia-Zubia et al. [2006]: This project has evolved during the last 2 decades, starting in early 2000's, developing teaching complex programmable logic devices (CPLDs) and field-programmable gate array (FPGAs). This system supports multiple laboratories in a distributed network supported by an RLMS.

—REMLABNET II Schauer et al. [2014]: REMLABNET is an open RLMS system available for universities and secondary research based teaching schools.

2.8 Implementation

The defined RLMS components can be applied in systems for either virtual, remote or hybrid laboratories, considering the remote and hybrid categories the more challenging categories due to the combination of software and hardware components. This creates problems of synchronization and consistency of the laboratories data.

Implementations of the RLMS should take in to account the restrictions of remote laboratories for managing concurrent users. According to the type of online resource, it is possible to improve the availability and scalability of the system, managing different approaches for the users access. For instance, for measurement tasks that do not require to much time to be executed, a queue system can be used instead of a traditional appointments scheduling system.

Features of the RLMS can be applied in systems implementing remote controlling of hardware. Some examples are: tele-operation of robots or machinery for medicine, science, military or space exploration, as well as Internet of Things (IoT) devices that make extensive use of real-time tele-operation of hardware.

2.9 Consequences

Advantages

The system that implements RLMS can have features such as:

—***Accessibility***
Easy discovery and access to laboratory activities, that can be classified and accessible through the RLMS lab gallery component.

—***Concurrency***
The RLMS can facilitate the users distribution and management. Through the scheduler module, the RLMS can control the distribution of the hardware load. It can offer different types of non real-time interactions such as: batch executions or using pre-recorded videos of the laboratory experiments. Additionally, it can manage concurrent users in laboratory experiments with short execution time not requiring a dedicated session and using a queue mechanism to control the access.

—***Portability***
Having RLMSs compatible with laboratory learning objects facilitate the portability of those objects among different RLMS systems.

—***Reliability***
The RLMS can decide to turn off a specific lab when it is required, giving a guarantee about the correct management of the resources and the reliability of the laboratory experiences.

—***Scalability***
The RLMS can manage the resources independently, facilitating the addition of more laboratory stations and activities without losing performance, accountability and control of the available resources.

—***Adaptability*** Adaptability in terms of functionality can be provided by the RLMS using a laboratory experiment authoring module that allows the administrators to create, modify and update laboratory experiments.

—***Security and Privacy*** Through users role validation by the authorizer module, the RLMS can control the users access to some resources, preventing for example students accessing the laboratory resource manager.

Liabilities

Providers have to commit to keep the online laboratories available, having mirror labs and running inspections of the equipment periodically. Implementing maintenance procedures that not affect the current operation of the system. Teachers and other staff from the educational institution will need to develop a set of skills in terms of use of the laboratory authoring interfaces and for accessing and managing the reports. Security is a concern due the openness of the system. Allowing users (students ans teacher) to access the laboratory interfaces from home posses challenges in terms of the equipment surveillance and protection. This may require that online laboratories will be accessible only when personnel from the institutions is available to attend any emergency or abnormal situation.

2.10 Example Resolved

The educational institution has implemented the online laboratory system including the RLMS. This has simplified the management tasks for the lab administrator, having now information about the current state of the labs and its usage reports. Teachers have now the possibility of creating and combining different laboratory activities with different laboratory stations. Security and privacy has also improved by the inclusion of the users role validation across the system.

3. CONCLUSIONS

The advances in technology have greatly helped with the growth and development of educational institution infrastructures. Online educational programs are also growing in number, but there still issues for classes that require to develop in the students hands on experimentation skills. Online laboratories can help to solve the issue of acquisition of hands on experience. The challenge is to develop a system that it is reliable, scalable, adaptable, and secure. This is where the process of software engineering becomes important, helping in the definition of a set of standard models and patterns for these type of system, that will be helpful for future implementations.

More robust online laboratory systems will in the near future provide: interfaces that support different types of connections and devices, compatibility among providers technology, mobile hybrid online laboratories that mix virtual and real components, distributed laboratories infrastructures and lastly, a stronger integration with education virtual learning environments.

REFERENCES

AGRAWAL, A. AND SRIVASTAVA, S. 2007. Weblab: A generic architecture for remote laboratories. In *15th International Conference on Advanced Computing and Communications (ADCOM 2007)*. 301–306.

BIN, Q., YALI, Z., AND XIN, W. 2011. Design and implement of a remote laboratory management system. In *2011 International Conference on Electronics, Communications and Control (ICECC)*. 4240–4243.

BROWN, F. AND FERNÁNDEZ, E. B. 2004. A pattern system for access control. In *DBSec*.

BUSCHMANN, F., MEUNIER, R., ROHNERT, H., SOMMERLAD, P., AND STAL, M. 1996. *Pattern-Oriented Software Architecture - Volume 1: A System of Patterns*. Wiley Publishing.

DUAN, B., LING, K. V., MIR, H., HOSSEINI, M., AND GAY, R. K. L. 2005. An online laboratory framework for control engineering courses. *International Journal of. Engineering Education 21,* 6, 1068–1075.

GARCIA-ZUBIA, J., DE IPINA, D. L., ORDUNA, P., AND HERNANDEZ-JAYO, U. 2006. Experience with weblab-deusto. In *2006 IEEE International Symposium on Industrial Electronics*. Vol. 4. 3190–3195.

GUSTAVSSON, I., ZACKRISSON, J., HAKANSSON, L., CLAESSON, I., AND LAGO, T. 2007. The visir project - an open source software initiative for distributed online laboratories. *Proceedings of the 2007 REV Conference*.

HARWARD, V. J., DEL ALAMO, J. A., LERMAN, S. R., BAILEY, P. H., CARPENTER, J., DELONG, K., FELKNOR, C., HARDISON, J., HARRISON, B., JABBOUR, I., LONG, P. D., MAO, T., NAAMANI, L., NORTHRIDGE, J., SCHULZ, M., TALAVERA, D., VARADHARAJAN, C., WANG, S., YEHIA, K., ZBIB, R., AND ZYCH, D. 2008. The ilab shared architecture: A web services infrastructure to build communities of internet accessible laboratories. *Proceedings of the IEEE 96,* 6, 931–950.

LANCHAS, V. M., GALLARDO, A., RICHTER, T., BELLIDO, L., DEBICKI, P., AND VILLAGRÁ, V. A. 2011. A rig booking system for on-line laboratories. *2011 IEEE Global Engineering Education Conference (EDUCON)*, 643–648.

LOWE, D., MURRAY, S., LINDSAY, E., AND LIU, D. 2009. Evolving remote laboratory architectures to leverage emerging internet technologies. *IEEE Transactions on Learning Technologies 2,* 4, 289–294.

PRIEBE, T., FERNÁNDEZ, E. B., MEHLAU, J. I., AND PERNUL, G. 2004. A pattern system for access control. In *DBSec*.

SCHAUER, F., KRBECEK, M., BENO, P., GERZA, M., PALKA, L., AND SPILAKOVÃĄ, P. 2014. Remlabnet - open remote laboratory management system for e-experiments. In *2014 11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. 268–273.

ZAPATA-RIVERA, L. F. AND LARRONDO-PETRIE, M. M. 2016. Models of collaborative remote laboratories and integration with learning environments. *International Journal of Online Engineering 12,* 9.

ZUTIN, D. G., AUER, M. E., MAIER, C., AND NIEDERSTATTER, M. 2010. Lab2go: A repository to locate educational online laboratories. In *IEEE EDUCON 2010 Conference*. 1741–1746.