The Remote Laboratory Management System (RLMS) Pattern

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Online laboratories have become a solution 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 and security. Additionally current online laboratory systems implementations do not follow any software design pattern or reference architecture for their design, for those reasons it 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.

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

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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 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, and security, 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 knowledge 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 Laboratory (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 Support** 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 Experiment** to create SLLOs.

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 experiments and RLMSs developers.

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

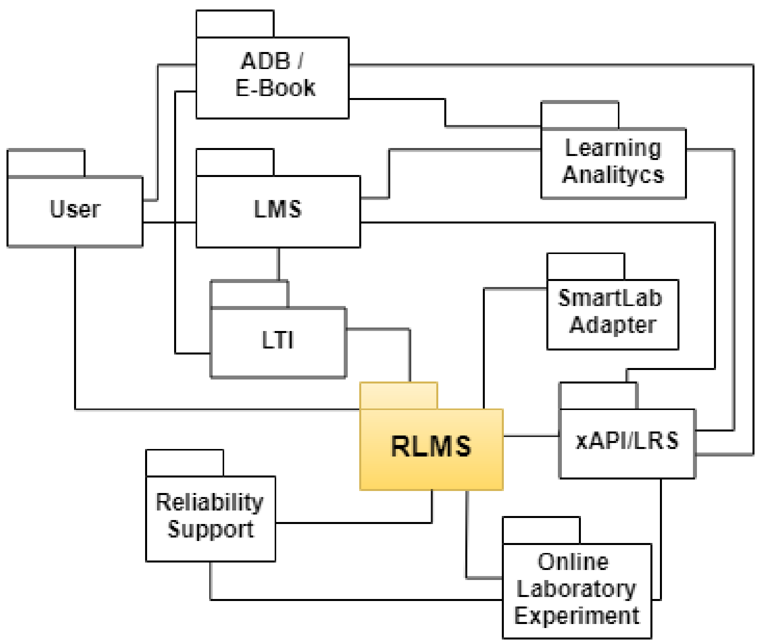

Fig. 1: RLMS as module of the SARL System

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 manages online laboratory experiments. It provides functions such as: authentication, authorization, scheduling, lab resources management and optionally laboratory authoring tools and management of the laboratory experiments activities.

2.3 Example

An educational institution offers its students a set of laboratory experiments. One of the students needs to have access to a different type of experiment that is not available in the school. He found another institution that has an online experiment available in their laboratory facilities. But this online laboratory experiment will need to be integrated and customized for its use. Additional challenges are: having a feature to identify the remote users using the laboratory experiment and also for scheduling appointment to access the lab experiment, giving the students specific slots of time in which this lab will be available for external access. Finally a mechanism is required for reporting to the institution that owns the laboratory experiment, information about the users and results of the laboratory activities.

2.4 Context

Implementations of online laboratory systems have been increasing rapidly during the last decade. Online education programs need to provide hands-on experience to their online students. In order to provide support for a large number of users and a correct management of the laboratory experiments, it is important to have a software platform that centralizes the access and the connections to remote experiments.

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.

(Harward et al. 2008) defined a Laboratory Service Broker that integrates distributed experiments. Additionally, (Bin et al. 2011) defined 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.

2.5 Problem

The problem is how to provide services of online laboratories to a set of distributed users, having a system that consider aspects such as: accessibility, concurrency, portability, reliability, scalability, adaptability and, security and privacy.

The solution to these problems is affected by the following forces:

—***Accessibility***

The remote laboratories should support easy access to let users perform a variety of available experiments.

—***Concurrency***

The remote laboratories experiments must allow concurrent users to maximize the number of user attended during an specific period of time on each laboratory station.

—***Portability***

Portability of the remote laboratory will allow transferring a lab from one system to another, where each implementation requires to follow the definitions of the host RLMS.

—***Reliability***

Due to the extensive use of software and hardware in remote laboratory systems, it is important to have reliable labs to guarantee the availability labs and consistency of the results.

—***Scalability***

When the number of users increases, the system should be able to be upgraded without affecting the quality of the service in terms of usability and performance.

—***Adaptability***

Remote laboratories should have the ability to be adapted, updated or modified by users with the respective permissions.

—***Security and Privacy***

Online laboratory system may implement modules to support security and privacy. This can help to keep protected the laboratory equipment, facilities, as well as the users accounts and personal information.

2.6 **Solution**

The user has access to the online laboratory experiments through the use of the RLMS system, that offers support for laboratory experiments management.

2.6.1 ***Structure***. The RLMS is composed by: the user *Authenticator*, based on (Fernández 2013), that validates the user identity. The *Authorizer* based on the authorization pattern proposed by (Fernández 2013), 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 *Logger/Auditor* proposed by (Fernández 2013) records all the activities and actions that are relevant for security and that could affect the operation of the system. The *SessionManager*, based on the session pattern proposed by (Fernández 2013), 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 *LabScheduler* manages the user booked sessions with the laboratory experiments. The *LabResourceManager* is a critical component that controls the availability of the laboratories stations, activities and laboratory experiments. 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 *LabResourceManager* and that can later be posted as an available resource in the *LabGallery*. All the logs of the systems are collected by the **Logs and Reports** module, it is connected with the resource manager, serving as an information source for the reports generation and to provide relevant information for the reliability support. Figure 2 presents the Remote Laboratory Management System pattern.

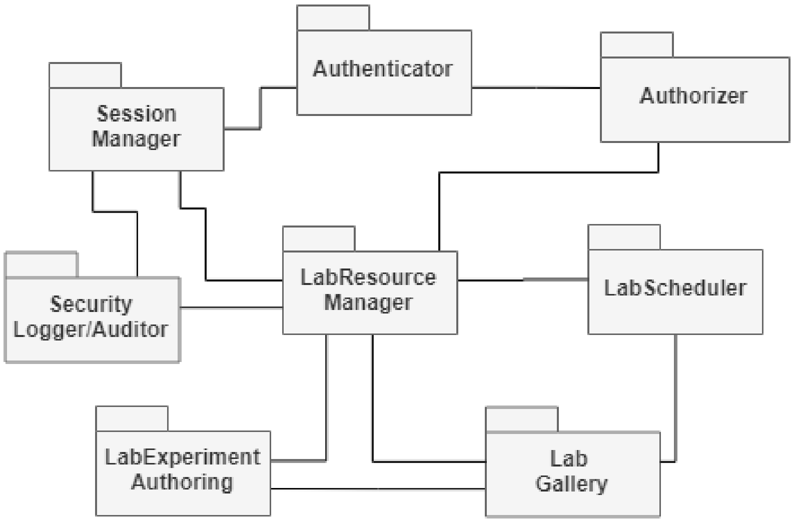

Fig. 2: Remote Laboratory Management System Pattern

2.6.2 ***Dynamics***. We present two use cases that describe some of the dynamic aspects of the pattern. Figure 3 shows the sequence diagram of the use case for a teacher or administrator creating a new laboratory experiment, and figure 4 presents the sequence diagram of the use case for a user with the student role, accessing an available laboratory.

Use Case:	Creating a laboratory experiment
Summary:	An actor 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)
Pre-condition:	The actor has the rights to access the system with the teacher or lab administrator role
Description:	1. The actor access the system using his user and password 2. The actor requests to create a laboratory experiment in the LabExperimentAuthoring component 3. The LabExperimentAuthoring asks to the Authorizer for access permission with the user id and role 4. If the actor is authorized, he can access LabExperimentAuthoring component 5. The actor starts with the first step describing the activity(s) 6. The actor selects the laboratory station(s) from the available resources in the LabResourceManager 7. The actor finalizes the process including administrative information (topic, activity duration, class, topic, difficulty level, etc) 8. The actor request to the LabExperimentAuthoring to save the laboratory experiment as a Laboratory Learning (LLO) 9. LabExperimentAuthoring stores the LLO in the LabResourceManager the as one of the available resources
Post-condition:	If the resource was created correctly, it will be available for the students. The teacher can either create a new laboratory resource or edit an existing resource.

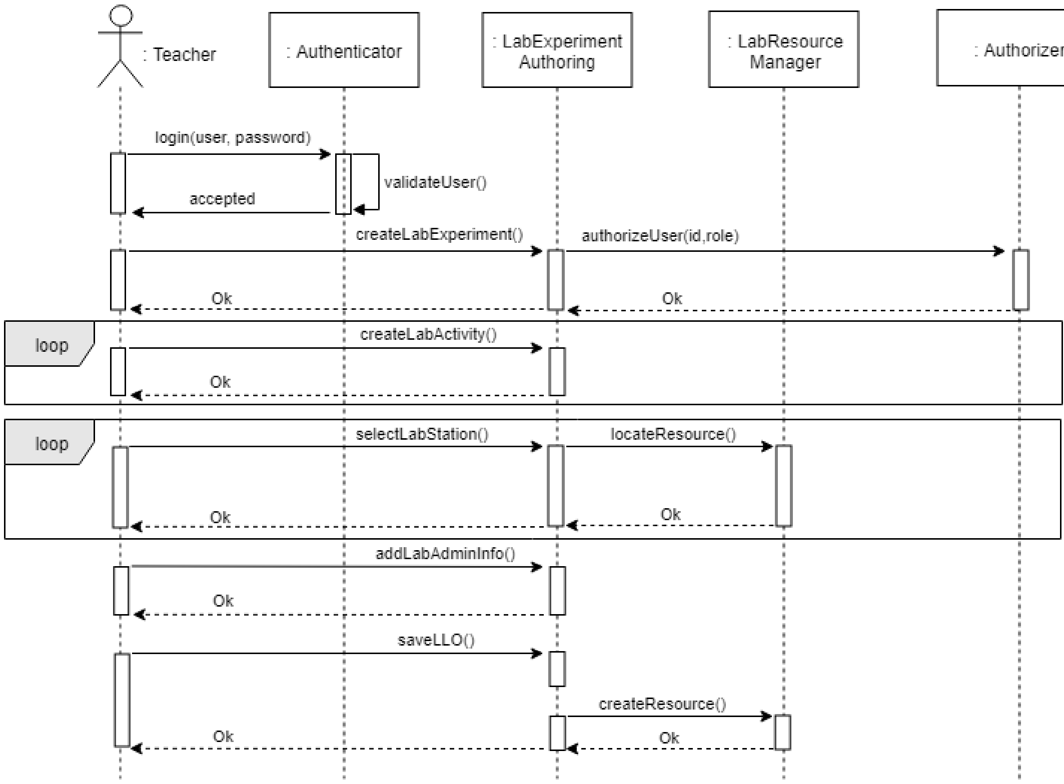

Fig. 3: Sequence diagram use case creating a laboratory experiment

Use Case:	Accessing a laboratory experiment
Summary:	An actor in a role of student requests accessing a laboratory experiment that he or she has already scheduled
Actors:	Person (Role student)
Pre-condition:	The actor has the rights to access the system with the student role and had an appointment scheduled
Description:	1. The actor requests access to the laboratory experiment from the LabGallery 2. The LabGallery validates with the LabScheduler if the actor has an active appointment 3. If the appointment is scheduled, a laboratory connection request is sent to the LabResourceManager 4. The LabResourceManager validates with the Authorizer if the actor role has permission to access the laboratory experiment 5. The user access to the laboratory is granted
Post-condition:	If the actor got access to the lab he can start performing the lab experiment, if not, he has to schedule an appointment for the same or other existing lab resource.

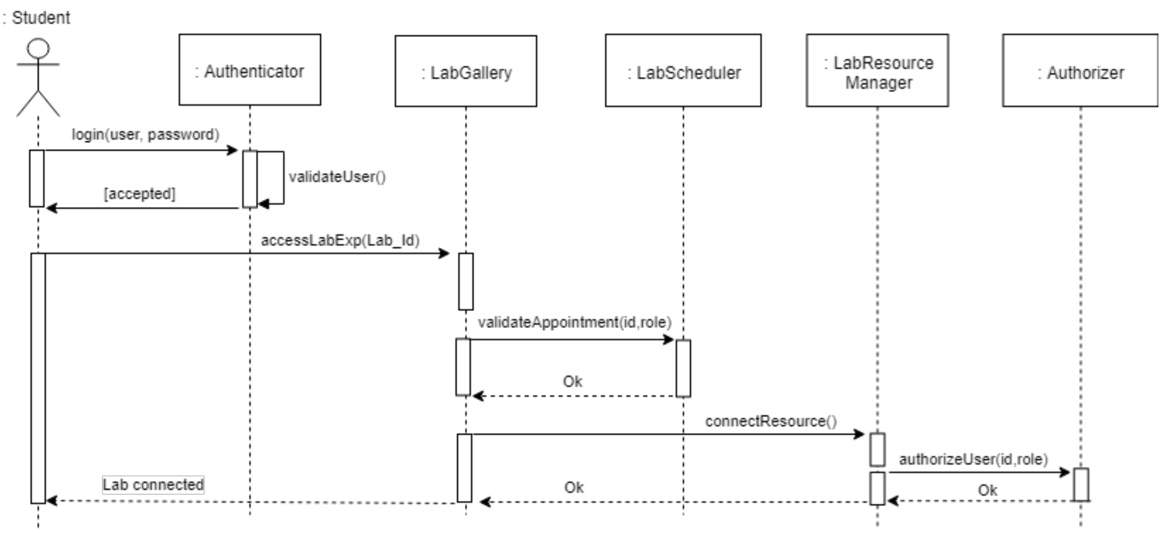

Fig. 4: Sequence diagram use case accessing a laboratory experiment

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

2.7 Related Patterns

—The Authenticator pattern (Fernández 2013) defines the identity verification of a subject trying to access the system. The use of credential such as user and password is one of the authentication protocols available.

—Authorization pattern (Fernández 2013) defines who is authorized to access some specific resource in the system.

—Role-Based Access Control pattern (Fernández 2013) defines the structure of roles for accessing a protected object.

—Security Logger/Auditor pattern (Fernández 2013) defines the mechanism for tracking users actions, this helps to determine what the user did and when.

—Book The Resource pattern (Vaccare-Braga et al. 1999) describes the management of resources reservation.

—Reservation and Use of Reusable Entities patter (Fernández and Yuan 1999) describes how to make a reservation for a reusable entity and its subsequent use.

2.8 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 of 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.

2.9 **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, creating 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 too much time to be executed, a queuing 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.

2.10 **Consequences**

Advantages

This pattern offers the following advantages.

—***Accessibility***
The user can discover and access the laboratory experiments and activities through the internet.

—***Concurrency***
The RLMS can facilitate the users load 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 facilitates 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. Additionally features such as: encryption and detection of security anomalies in the system (DoS and DDos attacks, malicious code insertion, Databases code injection, etc).

Liabilities

Four major liabilities of this pattern include: cost, maintenance, training and security.

—Ensuring the availability, concurrency of users and scalability of a Online Laboratory infrastructure has a big cost, for instance, the deployment of mirror laboratory stations that can supply the user demands, as well as the costs related with servers and network devices that can guarantee the good performance of the system.

—Providers have to commit to keep the online laboratories available, 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 be trained 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 and 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.

2.11 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 role based access control RBAC.

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 hands on experimentation skills for their students. 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.

Security and privacy aspects are not commonly implemented in online laboratory systems, this creates risks for users and also for the laboratory facilities. In order to improve this situation, security controls should be defined since the design stage of RLMSs or laboratory experiments. Finally, to increase the security of the laboratory systems, it is important to implement security patterns since early stages of its development.

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