Welcome to the REV2013 Conference in Sydney, Australia
6 - 8 February 2013

Photo: Andrew Gregory. Courtesy Destination New South Wales

REV2013: 10th International Conference on Remote Engineering and Virtual Instrumentation

"Moving from design to innovation and impact"

REV2013 is being held in Sydney, Australia. Sydney is the largest and most dynamic city in Australia. Attending REV2013 will give you an opportunity to experience Sydney's stunning harbour, wonderful climate, friendly people, and numerous other attractions, whilst participating in an exciting conference program.

REV 2013 is the tenth in a series of annual events concerning the area of remote engineering and virtual instrumentation. The REV conferences are the annual conferences of the International Association of Online Engineering (IAOE) (**www.online-engineering.org**). The general objective of this conference is to demonstrate and discuss fundamentals, applications and experiences in the field of remote engineering and virtual instrumentation. With the globalization of education the interest in and need of teleworking, remote services and collaborative working environments now increases rapidly. Another objective of the symposium is to discuss guidelines for education in university level courses for these topics. REV 2013 offers an exciting technical program as well as academic networking opportunities during the social events.

Scope of the conference

Remote Engineering and Virtual Instrumentation are very future trends in engineering and science. Due to:

- the growing complexity of engineering tasks,
- more and more specialized and expensive equipmentas well as software tools and simulators,
- the necessary use of expensive equipment and software tools/simulators in short time projects,
- the application of high tech equipment also in SME's,
- the need of high qualified staff to control recent equipment,
- the demands of globalization and division of labour,

it is increasingly necessary to allow and organize a shared use of equipment, but also specialized software as for example simulators. Organizers especially encourage people from industry to present their experience and applications of remote engineering and virtual instruments.

The general objective of this conference is to discuss fundamentals, applications and experiences in the field of remote engineering and virtual instrumentation. The use of virtual and remote laboratories is one of the future directionsfor advanced teleworking, remote service and e-working environments. Another objective of the symposium is to discuss guidelines for educationin university level courses for this topic.

Links to earlier conferences

Topics of interest include (but are not limited to)

- Virtual and remote laboratories
- Remote process visualization and virtual instrumentation
- Remote control and measurement technologies
- Online engineering
- Networking and grid technologies
- Mixed-reality environments for education and training
- Education and operation interfaces, usability, reusability, accessibility
- Demands in education and training, e-learning, blended learning, m-learning, and ODL
- Open educational resources (OER)
- Teleservice and telediagnosis
- Telerobotics and telepresence
- Support of collaborative work in virtual engineering environments
- Teleworking environments
- Telecommunities and their social impacts
- Present and future trends, including social and educational aspects
- Human computer interfaces, usability, reusability, accessibility
- Innovative organizational and educational concepts for remote engineering
- Standards and standardization proposals
- Products
- Military wireless applications
- Information security
- Telemedicine
- Renewable energy
- Applications and experiences.

Program Summary

The conference will have a core program run over 2 days (6th and 7th February). There will also be a 3rd day for the conference involving a social trip to support networking and following up on the conference discussions in a more relaxed setting. The cost of the trip is included in the conference registration fee. And the Global Online Laboratory Consortium will be hosting two day-long meetings of the Technical and Education sub-committees immediately prior to the conference.

Monday 4th February	Pre-conference Meeting: GOLC Technical Committee
Tuesday 5th February	Pre-Conference Meeting: GOLC Education Committee Pre-Conference Workshop: Introduction to Remote Laboratories
Wednesday 6th February	**REV2013 Day 1 (Remote Engineering Foundations)** **Keynote; Papers Sessions; Best Paper Session**
Thursday 7th February	**REV2013 Day 2 (Remote Engineering Applications)** **Workshops; Paper Sessions; Keynote**
Friday 8th February	REV2013 Day 3 Social Trip to Wildlife Park; Blue Mountains; Harbour Cruise

Other opportunities to participate

Thematic workshops / tutorials / technical sessions, as well as interactive demonstrations and exhibitions, may also be proposed. Prospective organisers of other REV2013 events are encouraged to contact the Conference Chair.

Conference language

English.

Proceedings

The proceedings will be published on CD by the International Association of Online Engineering (IAOE), and they will be indexed by IEEE Xplore.

Interesting papers may be published in the International Journal of Online Engineering (iJOE), **www.online-journals.org/i-joe/** .

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Grid Remote Laboratory Management System

Sahara Reaches Europe

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***Abstract*— Remote laboratories have become a useful educational tool. There is a common, though often not well-articulated, distinction between the remote laboratory that provides the experimental experience for students, and the supporting Remote Laboratory Management System (RLMS) that provides ancillary services such as access control and apparatus monitoring. Whereas some remote laboratories are developed specifically within the context of a given RLMS, many more have been developed as stand-alone experiments. This paper explores the challenges in integrating existing remote laboratories into a separate RLMS. A case study is described that makes use of Sahara – an evolving RLMS developed under the Australian Labshare project – describing its architecture, main features, capabilities, limitations and the future challenges. The paper then reports preliminary observations with regard to implementing Sahara within a European university (the Electrical & Computer Engineering Department of the Spanish University for Distance Education (UNED)) as part of a strategy of creating a grid RLMS for the pool of pre-existing remote laboratories used within the UNED education programs.**

Keywords-component; e-learning; engineering education; Labshare; online learning; Sahara

I. INTRODUCTION

Laboratories have long been acknowledged as a key element and an indispensable integral component of engineering education; they pave the way for students to become familiar with instruments and thus with the industrial real world. Unfortunately, laboratories are generally costly to develop, acquire, administrate, and maintain and they often have limited utility beyond specific courses and extremely low overall utilization rates [1]. Traditional laboratories require students to be physically present in order to interact with equipment, limiting both student flexibility and the sharing of facilities. Taken together, these factors represent a major logistical challenge to most educational institutions [2]. The current inflexible operation of, and constrained access to physical laboratories, in addition decreasing budgets and increases in student numbers have put pressure on universities in the delivery of effective practical laboratory education [3]. The recent emergence of appropriate Information and Communication Technology (ICT) enables physical laboratory equipment to be monitored and manipulated through the internet, and has therefore facilitated the development of online or remote laboratories [4]. It is important to note that remote laboratories are those laboratories that can be accessed and manipulated online; they differ from their virtual counterparts as they deal with real physical equipment rather than simulations. Remote laboratories have been shown to provide significant benefits compared to traditional hands-on laboratories Examples include increased time for student access to equipment, resource sharing between institutions to offset costs and a more versatile range of experimentation due to the mitigation of safety issues, being used in a secure environment with tightly constrained access which limits either intentional or unintentional misuse [5]. The earlier era of remote laboratory development saw more efforts directed at their technical architectures [6, 7] — preoccupations included experimenting with technologies for real-time audio and video streaming in an effort to overcome bandwidth limitations while ensuring service quality, and dealing successfully with the arbitration of multiple simultaneous connections to shared online laboratory apparatus and equipment. To a significant extent, many of these issues have been successfully overcome, with continuous, reliable and high quality services being maintained for much of the past decade. The focus of remote laboratory development is now moving towards more sustainable models that promotes both institutional and individual engagement [8]. Rather than individual academics custom building equipment for their specialized subjects, remote laboratory development is increasingly being carried out by multi-institution consortia [8]. There are numerous initiatives being either funded or proposed in order to create Remote Laboratory Management Systems (RLMSs) that provide a common online portal for accessing and administrating a wide pool of heterogeneous developed remote lab systems that might be distributed at several universities. Examples include WebLab Deusto [9], iLab [10], and Labshare [8]. This allows academics to take advantage of pre-existing tools to implement their experiments, rather than having to begin from scratch. While the main goal of most RLMS projects has been to provide access to a pool of stand-alone heterogeneous remote lab systems located at any university, most RLMS projects were tailored and customized primarily for specific experiments developed within the same project in order to verify the function and the performance of the proposed RLMS. A next step would be exploiting such systems and implementing them at non-partner universities in order to get more feedbacks and consequently analyze the associated challenges with integrating different types of remote lab systems.

In this paper a case study of such utilization is presented. A pool of pre-existing distinct remote laboratories, at the Electrical & Computer Engineering Department of the Spanish University for Distance Education (UNED), is wrapped into the Sahara RLMS developed within the Labshare project. Sahara is one of the most advanced RLMSs and has been successfully utilized by five Australian universities and deployed in their undergraduate engineering practices. Each of these universities participate by providing specific lab experiments that can be shared by the other partners creating a grid RLMS. The goal is to extend Sahara to include experiments from its first participating oversea and European university, UNED. The paper starts with providing a general overview on RLMSs and the Sahara architecture addressing the capabilities, features, limitations, and future challenges. The paper then reports preliminary observations with regard to implementing Sahara in the practices of various engineering disciplines at the Electrical & Computer Engineering Department of the UNED.

The rest of the paper is structured as follows. Section II discusses the general literature on remote laboratories and the emerging integration approaches. Section III describes the Sahara architecture highlighting its capabilities, features, limitations and the future works. Section IV reports on the role of Sahara the UNED and on the new labs to be added. Section V is dedicated to a general discussion on the faced issues and on other concerns pertinent to integrating different lab systems within Sahara. Finally, a conclusion is drawn in Section VI along with the future work and the upcoming research paths.

II. RELATED WORKS

Remote laboratories have been widely adopted across many disciplines of industrial electronics including embedded systems programming and their applications [11, 12], controlling of electrical machines [13-15], measurement of analog electronics circuits [16, 17], and programming Programmable Logic Devices (PLCs) [18, 19]. Along with the evolution of remote laboratories in the past decade, several approaches have arisen lately in order to create a generic architecture for provision of administrative and management tools, shared access, and even information about dispersed and heterogeneous remote lab systems that might be distributed across multiple universities. This may involve reusing pre-existing educational architectures such as Learning Management Systems (LMS) or creating an educational architecture that provides a set of services for its wrapped remote laboratories such as Remote Laboratory Management System (RLMS) and Remote Laboratory Metadata Repository (RLMR). The emergent related approaches for aforementioned purposes are classified as follows.

A. Integration with Learning Management Systems (LMSs)

A LMS is a software application that facilitates the provision of online classrooms education by means of integrated features such as administrative tools, synchronous and asynchronous communication tools, assessment and tracking tools, multimedia sharing tools, and standards compatibility. Even though, most of the features provided by LMSs are of crucial importance to practical sessions. They are typically confined to non-physical resources and doesn't support their practical counterparts [20]. The goal is to make use of all the services provided by open source LMSs such as Moodle [21], DotLRN [22] and Sakai [23], and apply them in supporting remote practical lab sessions as shown in Figure 1. Among the most noticeable initiatives are the LiLa project [24] and the middleware architecture described in [25-27].

B. Remote Laboratory Metadata Repository (RLMR)

Sharing remote laboratories and resources between universities avoids reinventing the wheel and building remote laboratories from scratch, and thus, yields to mutual benefits in terms of cost, time, availability and space. Unfortunately, there exist hundreds of remote laboratories developed at many universities without being reused by others owing to the lack of available information about these laboratories. To address these issues several approach such as LiLa, iLabCentral [28], and the Lab2go project [29], have been launched in order to create online metadata repositories that provide information about dispersed remote laboratories located at numerous universities. The metadata may cover developer University, scientific field, access URL, status, cost, language, etc. These approaches consider primary providing information on remote laboratories rather than providing administration and access.

C. Remote Laboratory Management System (RLMS)

Remote laboratories are usually not affordable and confined to the private usage of their owner university owing to the complexity of their interoperation. As mentioned earlier, inter-institutional sharing of remote laboratories is often considered to an important objective. Thus, creating remote laboratories able to be integrated in a generic and inter-institutional framework rather than individual academics custom building equipment for specific subjects is currently the trend in remote laboratories development. RLMSs provide an answer to these needs by providing a common portal for accessing and administrating a wide pool of heterogeneous developed remote laboratories that might be distributed at several universities in order to span their dissemination and inter-institutional operation. The pioneer RLMSs that have been adopted at many

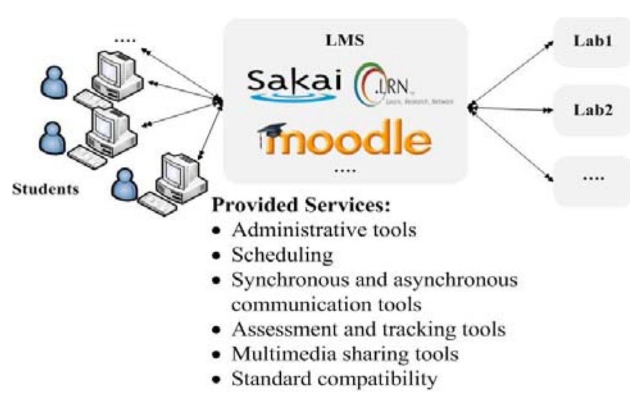

Figure 1. Topology or remote labs integrations with LMS.

universities include the iLab Shared Architecture (ISA) [10] and Sahara. Both offer similar functionalities but their architectures are different. ISA offers a relative comparative advantage in batched labs and its distributed architecture, whereas Sahara offers advantages for interactive labs, queuing, and seamless integration of new experiments [8, 30]. In this paper we deal with Sahara as a case study for our approach. Next, an overview on Sahara architecture is given.

III. SAHARA ARCHITECTURE

Sahara is the RLMS developed and adopted within the Labshare project [31]. “Labshare: National Support for Laboratory Resource Sharing” is an Australian project formed in late 2008 and led by the University of Technology Sydney (UTS). It is a joint initiative of the Australian Technology Network (ATN) partners: UTS; Curtin University of Australia; University of South Australia (UniSA); Royal Melbourne Institute of Technology (RMIT); and Queensland University of Technology (QUT). The project had funding of $3.8 million over 3 years, including $2.1m from the Australian Government's Department of Education, Employment and Workplace Relations (DEEWR), through the Diversity and Structural Adjustment (DSA) Fund, and the remainder contributed by the project partners. Labshare's mission is to create a nationally shared network of remote laboratories in the context of Australian higher education institutions, in order to address the issues of laboratory underutilization, accessibility, flexibility and foster the availability of high-quality experiments. It has developed both supporting software systems as well as an organizational model that will encourage and support cross-institutional sharing. This will result in higher quality labs that support greater student flexibility and improved educational outcomes, improved financial sustainability, enhanced scalability in terms of coping with student loads, and are developed and run by those with the best expertise. In order to build on this expertise, all Labshare ATN partners have since designed and constructed at least one remote experiment as part of the Labshare Project [1, 2].

A. *Terminology*

Remote laboratory terminology may vary from one remote laboratory project to another. The common adopted terminology terms in the Labshare project that are important to the subsequent discussions include [2]:

- **Device:** A single piece of equipment which forms part of a rig (e.g. a camera, a solenoid, a water tank, a PLC unit).
- **Rig Instance (Rig):** A single instance of a physical system made from various devices (including associated software and hardware) that can be used by one or more students in carrying out a distinct and discrete learning activity.
- **Rig Type:** The class to which a rig belongs, and within which any rig can be used interchangeably. A given institution (or laboratory provider) will often have more than one rig type, and for each rig type they may have multiple rigs.
- **Rig Collection (Collection):** The collection of homogeneous rigs, all of the same rig type, which are co-located and managed together.
- **Physical Hardware Laboratory (Laboratory):** Multiple collections of heterogeneous rigs, possibly belonging to multiple rig types, which are co-located and managed together.
- **Rig Pool (Pool):** The collection of homogeneous rigs, all of the same rig type, which may be distributed across multiple physical locations and managed by different organizations, but which can be treated as a single logical collection for access purposes.
- **Rig Capability:** A list of identifying tags which may be used to correlate rigs into collections to queue or book for. This allows, for example, multiple rig types to be collectively queued to get the first free rig in any of the rig types.

B. *Architecture Description*

The Sahara architecture is composed of three main software applications and each application is composed from a set of components. The components of the three applications intercommunicate with each other by SOAP message calls. Next, a brief description of each application is presented:

- **Rig Client:** It provides a software abstraction of a rig and it is the intermediary between the scheduling server and the physical hardware (the rig itself). Each rig has its own rig client. It is typically written in Java and usually resides in the same machine of the rig. It allows the rig provider with administrative tools to control and configure his rig machine such as testing, assigning a rig IP, listening port, and rig type, and registering the corresponding Web cam. Once the rig provider configures the rig, she puts it online to be registered in the scheduling server.
- **Scheduling Server:** The Scheduling Server is the heart of Sahara. It is written in Java and it carries out all the administrative tasks such as creating user classes, users, and user access keys, and registering all the rigs. The administrator configures the class details and assigns users, rig types or capability, and time reservation slots to that class. The arbitrator software component included in the scheduling server is responsible of allocating either the available registered rig from a rig type or a specific rig upon user request.
- **Web Interface:** The Web interface is the end-user portal for Sahara through which users are authenticated and log in, if they are assigned to a class. It is written in PHP, HTML and JavaScript.

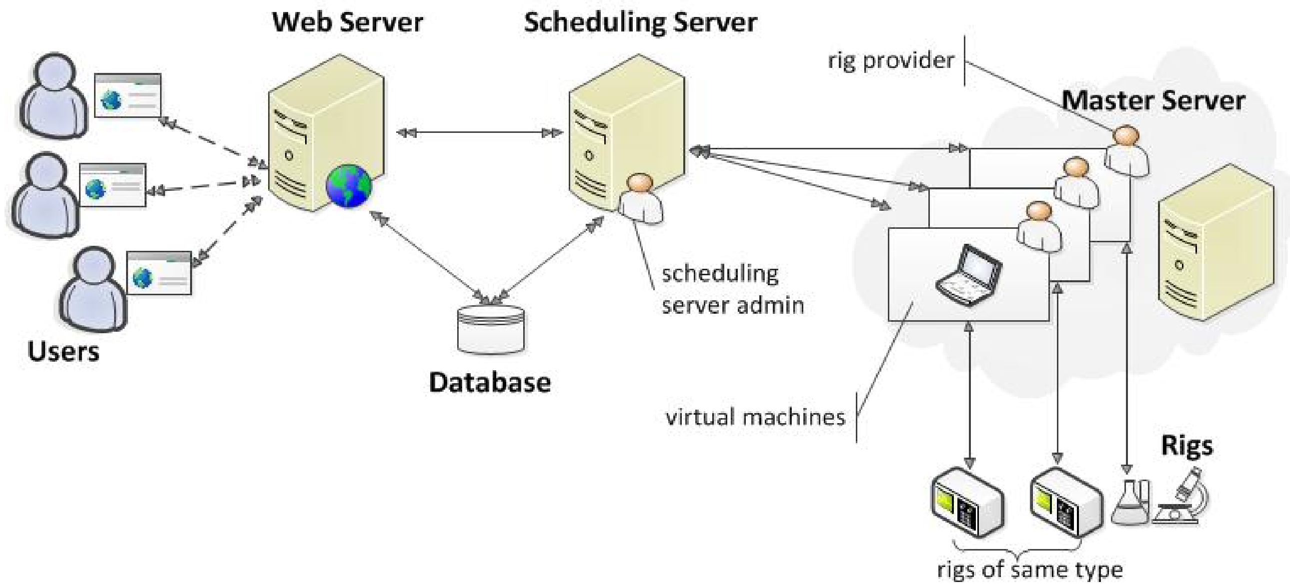

Figure 2. Sahara architecture.

Additionally, a database (MySQL or PostgreSQL) is needed and it communicates with the Web interface and the scheduling server. At UTS, all the rigs are installed in separate virtual machines, which are hosted in the same master server. The scheduling server that carries out the administration process of all the rigs is installed in a separate server. The web interface could either be installed in the same server of the scheduling server or separately. The overall architecture is depicted in Figure 2.

C. Features

Sahara allows institutions to use a common sharing platform to provide access to their experiments without the need for proprietary client software. In its most recent public release (v3.2, July 2012), Sahara supports the automatic allocation of individual rigs of the same type (replications), queuing of users and a reservation system for bookings. This combination allows remote laboratories with relatively few individual rigs of one type (typically 3-5) to cater for large numbers of students with little competition.

Access can be requested and then granted either to an individual rig, or any of a group of identical rigs of a rig type. Additionally, access can be granted in terms of a capability that is tagged to one or more rigs. Users have the ability to queue to use the rig as soon as available or to make a booking to use the rig at a specified time. A user will be assigned from the queue as soon as a rig that meets her criteria becomes available, or his booking becomes valid. Authentication is based either on a simple database authentication or interface to an institution's local authentication system such as Lightweight Directory Access Protocol (LDAP). Each user is associated with one or more user classes. Each user class is assigned the rigs they have permissions for, which consequently gives their members permissions to queue and/or make a booking for a rig, rig type or capability over a period of time. The queue for a rig is based on the priority associated with the user class. If the user has selected to queue for a rig type, they will be assigned the first available rig of that type; if the selection was for a specific rig, they will be assigned only when that rig becomes available. Sahara supports interactive rigs as well as rigs that have batch operation where the user is not required to interact with the rig in real time, and rigs that use both batch and interactive modes. Additionally Sahara can support monitoring rigs which collect data but do not require user interaction. Sahara allows collaboration on rigs by implementing different user modes. Master users, who are granted access and have full control of rigs, can allow slave users to join a rig session and either allow control (active slave user) or just allow visibility of session (passive slave user). A Webcam is enabled for all user types to monitor experiments [32].

A virtualization software (VMware) is used to set up multiple virtual PCs on a laboratory master server. The necessary software for each rig is installed in a single virtual machine. The arbitrator software system boots a Windows virtual machine on the master server and associates it with the relevant rig. The arbitrator authenticates requests for equipment and then allocate rig to students from the unused rig pool, queuing the allocation request when all are busy. The student creates a remote desktop connection to this virtual machine, runs the control application, and controls the rig. The control application is therefore running on the virtual machine at the master server (not on the remote user's computer). When a session of use is completed by a student, the arbitrator reclaims the rig, re-initializes it, and returns the rig to the free pool. Additionally, and instead of using a remote desktop connection, a rig user interface can be built, using Java classes which are written to send control commands to the rig control application that runs on a virtual machine, and embedded within the Sahara Web interface [33].

To enrich the application further support for student and tutor interaction has been designed. The open source Web based chat application “phpFreeChat” was adopted. The current implementation has support only for online text-based chat with rooms provided for students, tutors, as well as a room for each device, but the architecture will allow straightforward integration of video and audio interaction, as well as other coordination support tools. Once students have joined an experiment, tutors are able to cycle through the experiments and provide assistance, much like walking around a physical laboratory.

D. Added Experiments

Labshare currently provides access to more than a dozen types of rigs, with another dozen types under construction, and over 50 individual rigs [31], making it amongst the largest collection of its kind in the world. While the origin of these remote laboratories lies in a variety of engineering disciplines – electrical, telecommunication, mechanical, software, civil, geotechnical, and chemical engineering –, development has recently also expanded into physics and health sciences. These remote laboratories are accessible 24/7 from anywhere over the internet and provide a diverse set of laboratory-based educational experiences to staff and students at Australian universities - more recently also to Australian high schools and ultimately, globally.

E. Deployment and Feedbacks

As part of considering students’ utilization remote laboratories, a series of surveys were undertaken – and in particular a laboratory experiment involving the employment of a PLC to control a pair of pneumatically driven pistons. The surveys included an evaluation of students’ perceptions of whether they were controlling real equipment. Of 39 responses, 29 responded “yes” and 7 responded “no”. The most significant response, in terms of perceptions of reality, however related to the existence of a live video feed of the equipment, and the extent to which this made visible the “reality” of the experience – that being, an immediate contributor to “establishment reality”. Similarly, when they were asked if using the remote laboratory was more, or less, beneficial than a simulation 53% of respondents indicated more beneficial and only 7% indicated less beneficial. Of those who felt that it was more beneficial, a number of responses indicated that this was so because having the exposure to remote technology was more real – both in conducting the experiment and also more like what they would face in the future. Mentioned also was the fact that having something physically working felt more satisfying (in comparison to simulations which “just don’t feel right”), and it was more exciting so they felt more motivated. In other words, a sense of “feeling right” was considered a significant positive factor [34, 35].

F. Limitations and Future Challanges

Continuing improvement and overcoming current limitations of the Sahara architecture is one of the main tasks carried out by the Labshare partners. The upcoming challenges are centered but not limited to the following: allowing more group collaboration in online lab sessions and supporting concurrent access to a single virtual machine; improving bandwidth availability in order to increase quality of both interaction and contextualization of experiments; improving sensors and actuators making them flexible instead of their fixed position so that students would able to move, rotate, and zoom the cameras, and change the position of the actuator; enriching user interface and increasing interactive environment by relying on web standards such as AJAX and HTML5; adding more distributive capabilities to the Sahara architecture in order to allow sharing remote laboratories located at different universities in an efficient way, and decrease reliance on UTS; and giving more support to the dissemination of the architecture and the documentation.

IV. Deployment at the Spanish University for Distance Education (UNED)

The UNED is the second largest distance learning university in Europe, after The Open University, with 260,079 [36] enrolled students. A Learning Management System (LMS) is the main tool used at UNED to support the learning process and provide on-line access to digital educational resources. However, the provision of practical laboratories sessions on-line is still a major concern of the university. With the advent of E-Learning technologies, the Electrical and Computer Engineering Department at UNED [37] has been embarked on research into remote laboratories [38-42] and into the possibilities of creating a robust platform through which students could access the lab sessions online. This research involves either integrating remote laboratories into pre-existing LMSs or using stand-alone RLMS to afford the provision practical knowledge online in a managed way, in order to accommodate the needs of the huge number of online enrolled students. The deployment of Sahara in the department seems to be the best answer to these needs owing to its open source architecture, the seamless integration of remote laboratories in it, and the sustainability of its architecture as it has been proven to perform ideally at several universities.

Last but not least, the proposed laboratories that are already installed in the department and to be integrated in Sahara and deployed in the undergraduate engineering practices of the educational courses of 2012/2013 are the follows:

- **Virtual Instrument Systems in Reality (VISIR):** A remote laboratory for measuring and wiring analog electronic circuits online [43, 44], (Figure 3).
- **Embedded System Labs**: a collection of remote controlled programmable devices, for teaching VHL programming, including microcontroller, Field Programmable Logic Array (FPGA), and complex programmable logic device (CPLD) [45], (Figure 4).
- **FESTO Hydraulic Plant**: a laboratory for teaching fluids and control principals, with level, flow rate, pressure and temperature controlled systems to analyze fluid process, (Figure 5).

Figure 3. VISIR

Figure 4. Embedded System Labs.

Figure 5. FESTO Hydraulic Plant.

Figure 6. CompactRIO.

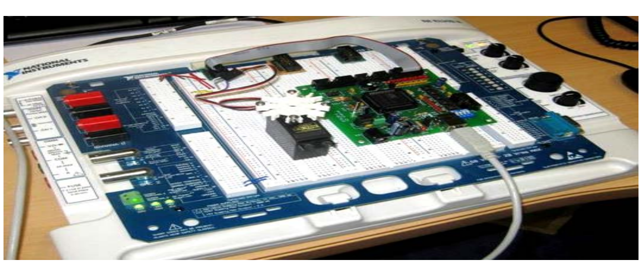

Figure 7. NI ELVIS II.

- **CompactRIO**: a reconfigurable embedded control and acquisition system that includes I/O modules, a reconfigurable FPGA chassis, and an embedded controller. It is used in a variety of embedded control and monitoring applications, (Figure 6).
- **NI ELVIS II**: a versatile design and prototyping educational integrated platform. It is suited for remote control and integrated with 12 of the most commonly used laboratory instruments (oscilloscope, DMM, function generator, power supply, dynamic signal analyzer, a bode analyzer, 2- and 3-wire current-voltage analyzer, arbitrary waveform generator, digital reader/writer, and impedance analyze). It has a variety of experiment plug-in boards and kits for teaching concepts in control, telecommunication, fiber optics, embedded design, bioinstrumentation, digital electronics, and FPGAs [46], (Figure 7).

V. DISCUSSION

Despite the inherent feature of Sahara or any other RLMS which is the ability to wrap new heterogeneous lab systems, still integrating such pool of dispersed laboratories represents a major challenge. Prior delving into details, if we were to consider premise generic remote lab architecture, it would be easier to define the principles of integration of different lab systems. Figure 8 depicts a foundational pattern upon most of remote laboratories are built. To a great extent, the majority of the developed remote labs follow this generic architecture. The common components are:

- *Lab server:* the server which contains the software that directly controls the instruments and it is physically connected to the instruments. LabVIEW and MATLAB are two commonplace commercial control software IDE, however a control software could be written from scratch by any high level programming language.
- *Web Server:* It is the server that hosts the RLMS of the lab (the access portal) through which user gets authenticated and accesses to the experiment. As well, it hosts the Graphical User Interface (GUI) or the user client software (the simulated workbench). Once the user gets authenticated through the access portal, she is granted access to the user client, which could be developed in one of these three forms:
    1. *Custom Built:* an embedded interface built with any programming language and communicates with the lab server through the TCP protocol.
    2. *LabVIEW Panel:* embedded interface provided by LabVIEW (via LabVIEW Web publishing tool) and thus it is only available for LabVIEW-based lab servers. It also communicates with the LabVIEW lab server software through the TCP protocol.

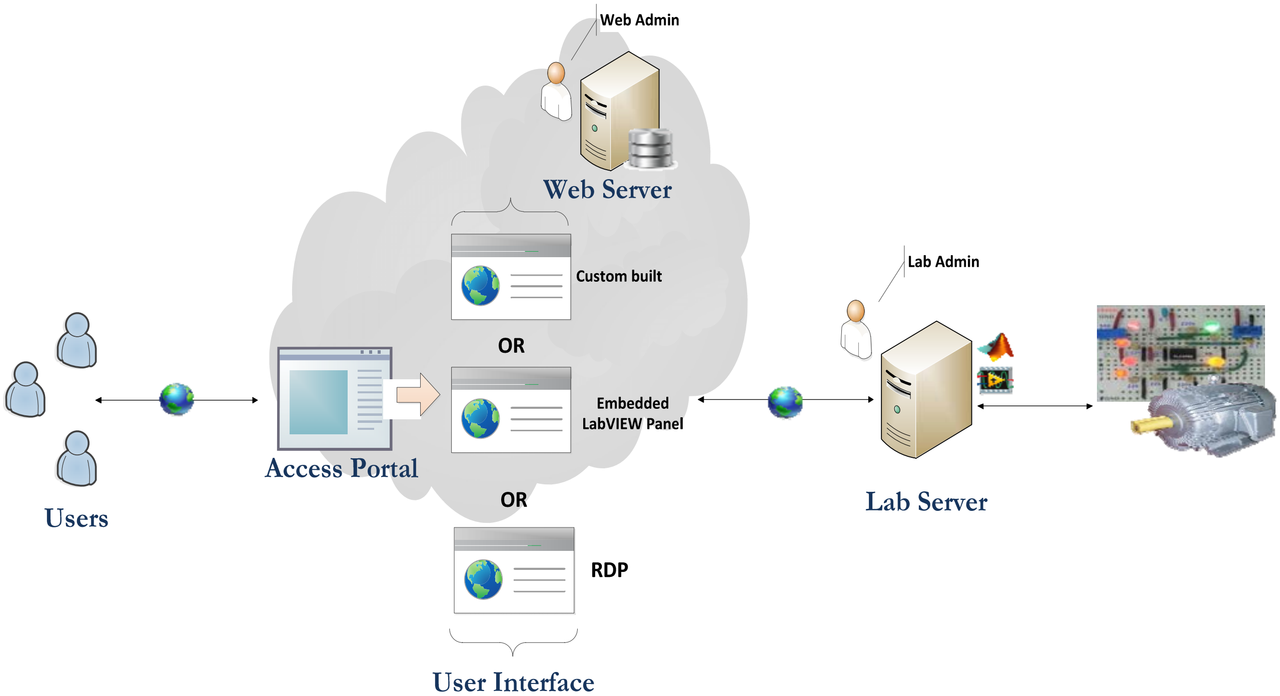

Figure 8. Generic remote lab architecture.

3. *Remote desktop Protocol (RDP):* In case that the user client can hardly be embedded in a web page. RDP could be the best option for accessing a server on which the user client is installed (as a software).

In our case, the user interface of the FESTO Hydraulic Plant, CompactRIO, and NI ELVIS II experiments are based on LabVIEW. LabVIEW is the lab server software and on the mean time it is the client software, with which the user directly interacts. This kind of labs could be seamlessly integrated into Sahara, by just using a virtual machine at the Sahara master server. Similarly, those of the Embedded System Labs, which are based on a simple web page for uploading a programmed file to the lab, which can also be easily hosted at a virtual machine. However, owing to the simplicity of creating a new user interface for such experiment it is recommended to avoid a virtual machine for three main reasons: 1) security issue, 2) compatibility issues, and 3) less flexibility when it comes to including external resources or scaffoldings along with the remote session.

Other issues arise when it comes to integrating more complex systems such as VISIR. In VISIR equipment is controlled by LabVIEW but the user interface is written in ActionScript (as a Flash application). In addition the system already has a complex integrated RLMS written in PHP which provides administration and different rules for user profiles. For instance a teacher profile could allow the design of experiments while a student profile will not allow this. The solution which has been chosen was creating an alternative tunnel based on TCP sockets between Sahara and the user interface software to permit privileges according to the Sahara user types and to remove the already existing RLMS that comes with VISIR. The GUI of VISIR built with flash would be embedded in the Sahara experiment web page. Thus each time a student access to the experiment web page, information about the student's identity, reserved hours, priority, and privileges would be sent to VISIR's GUI and student would see the available exercises accordingly. Administration issues such as preparing exercises and creating new courses would still be realized through VISIR's RLMS. Apparently, this could be a tedious approach for other universities.

The mentioned issues, however, have raised a new further research path focused on creating standard models for integrating different types of remote labs into RLMSs in a seamless. Recalling back the three common scenarios for developing a user client, an ideal RLMS should possess the capabilities of wrapping remote labs under any of these conditions which is unfortunately doesn't exists in any RMLS so far. For these purposes specific standard APIs should be defined addressing most of the common technologies for building user clients for remote labs. For instance, Figure 9 shows how a created standard API could be useful for wrapping LabVIEW-based remote labs into an RLMS. Creating such standards is a major interest among most of RLMS developers and among the partners of the Global Online Laboratory Consortium (GOLC).

VI. Conclusion & Further work

The development and use of RLMS is an emergent trend in E-learning, with increasing attention among many universities. Extending the implementation of RLMSs among universities is associated with new challenges owing to the diversity of remote lab systems in terms of technical and pedagogical point

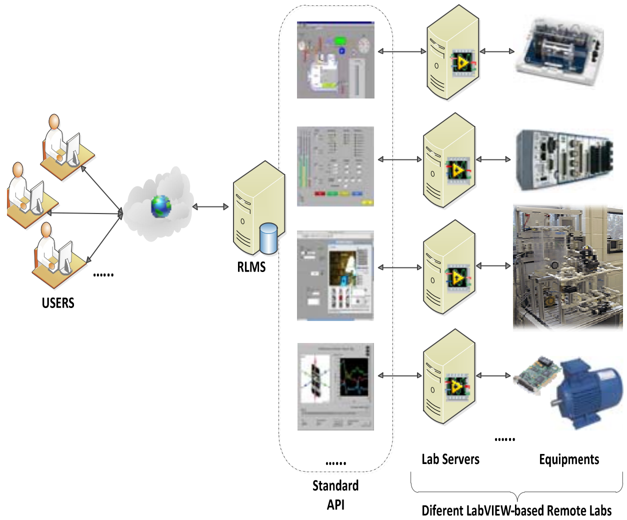

Figure 9. Standard API for wrapping LabVIEW-based Remote labs.

of view. In this paper a case study is presented highlighting many aspects of the Sahara architecture and the pre-existing pool of remote laboratories at UNED that are already being used in the practices of many engineering fields at UNED. Integrating diverse remote lab systems was associated with many challenges that are actually affronting also each university willing to wrap a pool of existing labs in a RLMS. The existing RLMSs are usually less flexible and can't cope with the variety of existing lab systems. Owing to this reason spreading of RLMSs among universities was hindered. Thus, our interest was shifted from developing RLMS into creating standard APIs based on loosely coupling solutions such as web services in order to leverage existing RLMS and to facilitate wrapping heterogeneous systems with each other . This will be the major focus of our future research path.

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REFERENCES

[1] D. Lowe, S. Murray, L. Weber, and M. d. l. Villefromoy, "LabShare: Towards a National Approach to Laboratory Sharing," in *20th Australasian Association for Engineering Education Conference*, University of Adelaide, 2009.

[2] D. Lowe, S. Conlon, S. Murray, L. Weber, M. de la Villefromoy, E. Lindsay, A. Nafalski, W. Nageswaran, and T. Tang, "Labshare: Towards Cross- Institutional Laboratory Sharing," in *Internet Accessible Remote Laboratories: Scalable E-Learning Tools for Engineering and Science Disciplines*, ed: IGI Global, 2012, pp. 453-467.

[3] T. Kostulsk and S. Murray, "The National Engineering Laboratory Survey: A Review of the Delivery of Practical Laboratory Education in Australian Undergraduate Engineering Programs," AustraliaDecember 2010.

[4] J. E. Corter, J. V. Nickerson, S. K. Esche, C. Chassapis, S. Im, and J. Ma, "Constructing reality: A study of remote, hands-on, and simulated laboratories," *ACM Trans. Comput.-Hum. Interact.*, vol. 14, p. 7, 2007.

[5] S. K. Esche, "Remote experimentation - one building block in online engineering education," in *Proceedings of the 2002 ASEE/SEFI/TUB International Colloquium on Global Changes in Engineering Education*, Berlin, Germany, 2002.

[6] M. Tawfik, E. Sancristobal, S. Martin, G. Diaz, and M. Castro, "State-of-the-art remote laboratories for industrial electronics applications," in *Technologies Applied to Electronics Teaching (TAEE), 2012*, 2012, pp. 359-364.

[7] M. Tawfik, E. Sancristobal, S. Martin, R. Gil, G. Diaz, J. Peire, and M. Castro, "On the Design of Remote Laboratories," in *Global Engineering Education Conference (EDUCON), IEEE*, Marrakesh, 2012, pp. 1-6.

[8] D. Lowe, S. Murray, E. Lindsay, and L. Dikai, "Evolving Remote Laboratory Architectures to Leverage Emerging Internet Technologies," *Learning Technol., IEEE Trans.on*, vol. 2, pp. 289-294, 2009.

[9] J. Garcia-Zubia, P. Orduna, D. Lopez-de-Ipina, and G. R. Alves, "Addressing Software Impact in the Design of Remote Laboratories," *IEEE Trans. Ind. Electron.*, vol. 56, pp. 4757-4767, 2009.

[10] V. J. Harward, J. A. del Alamo, S. R. Lerman, P. H. Bailey, J. Carpenter, K. DeLong, C. Felknor, J. Hardison, B. Harrison, I. Jabbour, P. D. Long, M. Tingting, L. Naamani, J. Northridge, M. Schulz, D. Talavera, C. Varadharajan, W. Shaomin, K. Yehia, R. Zbib, and D. Zych, "The iLab Shared Architecture: A Web Services Infrastructure to Build Communities of Internet Accessible Laboratories," *Proceedings of the IEEE*, vol. 96, pp. 931-950, 2008.

[11] J. Hardison, D. Zych, J. A. d. Alamo, V. J. Harward, S. R. Lerman, S. M. Wang, K. Yehia, and C. Varadharajan, "The microelectronics WebLab 6.0--an implementation using web services and the iLab shared architecture," in *Exploring Innovation in Education and Research*, Tainan, Taiwan, 2005.

[12] J. d. J. Rangel-Magdaleno, J. R. Rivera-Guillen, R. d. J. Romero-Troncoso, and R. A. Osornio-Rios, "FPGA-Matlab-based open core for three-time controllers in automatic control applications," *Comput. Appl. in Eng. Educ.*, 2011.

[13] A. Tekin, F. Ata, and M. Gökbulut, "Remote control laboratory for DSP-controlled induction motor drives," *Comput. Appl. in Eng. Educ.*, 2010.

[14] I. Colak, S. Demirbas, S. Sagiroglu, and E. Irmak, "A novel web-based laboratory for DC motor experiments," *Comput. Appl. in Eng. Educ.*, vol. 19, pp. 125-135, 2011.

[15] M. Tawfik, E. Sancristobal, S. Martín, C. Gil, P. Losada, G. Díaz, and M. Castro, "Design of Practical Activities in Electronics Using Visir Remote Laboratories," in *VII International Conference on Engineering and Computer Education (ICECE 2011)*, UMINHO – University of Minho, Guimarães, 2011.

[16] M. Tawfik, E. Sancristobal, S. Martin, C. Gil, P. Losada, G. Diaz, and M. Castro, "Remote laboratories for electrical & electronic subjects in new engineering grades," in *IEEE Fomento e Innovación con Nuevas Tecnologías en la Docencia de la Ingeniería (FINTDI)*, 2011, pp. 1-6.

[17] D. A. H. Samuelsen and O. H. Graven, "Low Cost Implementation of Remote Lab with Large Number of Configurations for a BJT Amplifier," *Int. J. of Online Eng. (iJOE)*, vol. 7, pp. 31-36, 2011.

[18] M. Domínguez, J. J. Fuertes, M. A. Prada, S. Alonso, and A. Morán, "Remote laboratory of a quadruple tank process for learning in control engineering using different industrial controllers," *Comput. Appl. in Eng. Educ.*, 2011.

[19] O. G. Bellmunt, D. M. Miracle, S. G. Arellano, A. Sumper, and A. S. Andreu, "A distance PLC programming course employing a remote laboratory based on a flexible manufacturing cell," *Education, IEEE Transactions on*, vol. 49, pp. 278-284, 2006.

[20] M. Tawfik, E. S. Cristobal, A. Pesquera, R. Gil, S. Martin, G. Diaz, J. Peire, M. Castro, R. Pastor, S. Ros, and R. Hernandez, "Shareable educational architectures for remote laboratories," in *Technologies Applied to Electronics Teaching (TAEE), 2012*, 2012, pp. 122-127.
[21] (2012). *Moodle.org*. Available: http://moodle.org/
[22] (2012). *.LRN Project Site*. Available: http://openacs.org/projects/dotlrn/
[23] (2012). *Sakai Project* Available: http://sakaiproject.org/
[24] T. Richter, D. Boehringer, and S. Jeschke, "LiLa: A European Project on Networked Experiments," in *REV 2009: 6th International Conference on Remote Engineering and Virtual Instrumentation*, Bridgeport, USA, 2009.
[25] E. Sancristobal, M. Castro, S. Martin, M. Tawkif, A. Pesquera, R. Gil, G. Diaz, and J. Peire, "Remote labs as learning services in the educational arena," in *IEEE Global Eng. Educ. Con. (EDUCON)* 2011, pp. 1189-1194.
[26] M. Tawfik, E. Sancristóbal, S. Martín, C. Gil, A. Pesquera, S. Ros, R. Pastor, R. Hernández, G. Díaz, J. Peire, and M. Castro, "Towards a Better Deployment of Remote Laboratories in Undergraduate Engineering Education," in *Using Remote Labs in Education: Two Little Ducks in Remote Experimentation*, J. G. Zubía and G. R. Alves, Eds., ed Bilbao: University of Deusto, 2011.
[27] R. Gil, E. S. Cristóbal, M. Tawfik, S. Martín, A. Pesquera, G. Díaz, A. Colmenar, J. Carpio, J. Peire, and M. Castro, "Applications and Security in the Practical Competitiveness Implementation within Learning Environments," *ARBOR Ciencia, Pensamiento y Cultura*, vol. 187, December 2011.
[28] (2012, May 1). *iLabCentral - The place to share remote online laboratories*. Available: http://www.ilabcentral.org/
[29] M. E. Auer, D. G. Zutin, C. Maier, and N. Michael, "Lab2go – a Semantic Framework to Exchange and Publish Online Laboratories," in *International Conference on Remote Engineering & Virtual Instrumentation (REV 2010)*, Stockholm, 2010, pp. 133-138.
[30] H. Yeung, D. Lowe, and S. Murray, "Interoperability of Remote Laboratories Systems," *Int. J. of Online Eng. (iJOE)*, vol. 6, pp. 71-80, 2010.
[31] (2012). *Labshare - Home*. Available: http://www.labshare.edu.au/
[32] S. Murray, D. Lowe, E. Lindsay, V. Lasky, and D. Liu, "Experiences with a hybrid architecture for remote laboratories," in *Frontiers in Education Conference, 2008. FIE 2008. 38th Annual*, 2008, pp. F1B-15-F1B-19.
[33] D. Lowe, C. Berry, S. Murray, and E. Lindsay, "Adapting a Remote Laboratory Architecture to Support Collaboration and Supervision," *International Journal of Online Engineering (iJOE)*, vol. 5, August 2009.
[34] D. Lowe, S. Murray, E. Lindsay, D. Liu, and C. Bright, "Reflecting Professional Reality in Remote Laboratory Experiences," in *Remote Eng. & Virtual Instrum. (REV)*, 2008, pp. 1-5.
[35] T. Kostulski and S. Murray, "Student Feedback from the First National Sharing Trial of Remote Labs in Australia," in *REV 2011 Proceedings*, Brasov, Romania, 2011, pp. 203 - 211.
[36] (2012, October 30). *Spanish University for Distance Education (UNED): Statistics*. Available: http://portal.uned.es/portal/page?_pageid=93,510355,93_20540449&_dad=portal&_schema=PORTAL
[37] (2012, May 1). *Departamento de Ingeniería Eléctrica, Electrónica y de Control (DIEEC) de la UNED*. Available: http://www.ieec.uned.es/
[38] (2012, May 1). *Research on Technologies for Engineering Education*. Available: http://ohm.ieec.uned.es/
[39] M. Castro, E. Sancristobal, S. Martin, R. Gil, M. Tawfik, A. Pesquera, M. J. Albert, G. Diaz, and J. Peire, "One Step Ahead in the Future of Labs: Widgets, Ubiquity and Mobility," in *Remote Eng. & Virtual Instrum. (REV) 2012*, Bilbao, 2012.
[40] S. Martín, E. S. Cristóbal, R. Gil, M. Tawfik, A. Pesquera, P. Losada, M. Latorre, G. Díaz, M. Castro, and J. Peire, "DIEEC (Departamento de Ingeniería Eléctrica, Electrónica y de Control), UNED," *Revista Iberoamericana de Informática Educativa (IE Comunicaciones)*, vol. 15, p. 9, January-June 2012 2012.
[41] E. Sancristobal, S. Martín, R. Gil, P. Orduña, M. Tawfik, A. Pesquera, G. Diaz, A. Colmenar, J. García-Zubia, and M. Castro, "State of art, Initiatives and New challenges for Virtual and Remote Labs," in *12th IEEE International Conference on Advanced Learning Technologies (ICALT)*, Rome, Italy, 2012.
[42] M. Tawfik, E. Sancristobal, S. Martin, R. Gil, A. Pesquera, E. Tovar, M. Llamas-Nistal, G. Diaz, J. Peire, and M. Castro, "Common Multidisciplinary Prototypes of Remote Laboratories in the Educational Curricula of Electrical & Computer Engineering," in *ASEE Annual Conference* San Antonio, Texas, 2012, pp. AC 2012-3227.
[43] M. Tawfik, E. Sancristobal, S. Martín, C. Gil, A. Pesquera, P. Losada, G. Díaz, J. Peire, and M. Castro, "A New Node in the VISIR Community," in *Remote Eng. & Virtual Instrum. (REV) 2011*, Brasov, Romania, 2011, pp. 16-22.
[44] M. Tawfik, E. Sancristobal, S. Martín, C. Gil, A. Pesquera, P. Losada, G. Díaz, J. Peire, M. Castro, J. García-Zubia, U. Hernández, P. Orduña, I. Angulo, M. C. C. Lobo, M. A. Marques, M. C. Viegas, and G. R. Alves, "VISIR: Experiences and Challenges," *Int. J. of Online Eng. (iJOE)*, vol. 8, pp. 25-32, February 2012 2012.
[45] M. Tauste, S. Martin, E. Sancristobal, M. Tawfik, J. Peire, and M. Castro, "Implementation of a remote laboratory for practices in FPGAs Programmable Logic Devices," in *1st Experiment@International Conference Remote & Virtual Labs (exp.at'11)*, Lisbon, Portugal, 2011.
[46] M. Tawfik, E. S. Cristobal, A. Pesquera, R. Gil, S. Martin, G. Diaz, J. Peire, M. Castro, P. Orduna, and J. Garcia-Zubia, "Putting fundamentals of electronic circuits practices online," in *Technologies Applied to Electronics Teaching (TAEE), 2012*, 2012, pp. 117-121.