

## On the use of cloud technologies to provide remote laboratories as a service

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**Abstract**— Cloud computing is a new paradigm that provides many features with regard to the efficient management of computing infrastructures. Thanks to it, scalable computing infrastructures can be developed, and lower power consumption can be achieved this being called *green computing*.

Distance education is a solution to the constant necessities of knowledge our society requires. In order to acquire practical competences in engineering education, the use of remote laboratories becomes a necessity more than just an option in the case of distance learning.

RELATED framework has been developed to permit structured development of remote laboratories. It presents a structured methodology of remote/virtual labs development and also provides common facilities as user management, booking, or basic visualization.

In the case that a high number of laboratories and students use RELATED, handling such amount of information becomes a major issue for the proper functionality of RELATED. This paper proposes the use of cloud technologies to enhance RELATED and to tackle these issues, and describes the cloud-based architecture under development at UNED.

**Keywords**-virtual remote laboratories; cloud; scalability;

### I. INTRODUCTION AND MOTIVATION

Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [1]. This new paradigm provides many benefits, among others [2] [3], lower cost of ownership, more efficient use of technical staff, cloud computing saves time, money and shortens production cycle, organizations can store more data than on private computer systems, or cloud computing offers much more flexibility than past computing methods.

The cloud represents a shift from the previous computing architectures in which computers had static software features, thus making users of such resources “fit” into those features. For example, if a shared computer has a Linux operating system installed along with some programs and libraries, users willing to run their applications on it had to make sure that their applications could run on such system. Hence, the use of computing systems could be considered as

“computer guided”, since users had to fit their applications to meet the features of the computer.

The cloud allows systems to dynamically provide the computing resources their users need, reducing expenses, energy consumption and improving on their scalability [4], [5]. Hence, if users want to run some applications in a cloud, it is the computer which has to “fit” into the needs of the users. In the example above, Virtual Machines (VM) can be instantiated dynamically to meet the requirements of the users. The cloud system can thereof be considered as a “user guided” system, since it is the computing resource that is adapted to the users’ needs. Furthermore, an appropriate cloud infrastructure manager (such as OpenNebula [6] or Eucalyptus [7]) can provide on demand instantiation, monitoring, and live migration of VMs. Consequently, fault tolerance and scalability are provided.

Another important point to keep in mind is the power consumption of the computers [5]. According to [8], datacenters now drive more in carbon emissions than both Argentina and the Netherlands. Thus, cloud infrastructures should be managed trying to reduce the power consumption of the computers, along with keeping efficient utilization of machines – this being called green computing.

The evolution of education and the increase in the knowledge necessities our society requires have created significant changes with regard to the way how the learning process takes place. Nowadays, there is a constant need to improve, to keep our knowledge up-to-date or to obtain knowledge on new topics – this being specially true in the case of technical studies, where technology is constantly evolving. Distance education is a solution to this problem, since it allows students to obtain practical knowledge without the space and time constraints of classical face-to-face education thus allowing them to fit their studies into their possibly tight schedules.

In our case, the National Distance Education of Spain (Universidad Nacional de Educación a Distancia, UNED), is the largest university in Spain, with more than 200,000 students. We provide totally distant education, so the use of remote laboratories to obtain practical knowledge on technical topics becomes a necessity more than just an option. For this, RELATED framework [9] has been developed to permit structural development of remote laboratories. It presents a structured methodology of remote/virtual labs development and also provides common facilities as user management, booking, or basic

visualization. In the case that a high number of laboratories and students use RELATED, handling such amount of information and such workload becomes a major issue for the proper functionality of RELATED. Besides, the use of cloud computing allows the adaptation of the RELATED infrastructures in order to fit it to the current or forecasted workload, thus allowing us to reduce expenses in terms of power consumption.

This paper proposes the use of cloud technologies to enhance RELATED and to tackle these issues. The structure of this paper is as follows. Section II briefs the RELATED framework, Section III presents the extensions harnessing cloud technologies under development at UNED, and Section IV presents conclusions and future work.

## II. RELATED FUNDAMENTALS

RELATED framework [9], [10] proposes a structured methodology of remote/virtual labs development and, also, provides common facilities as user management, booking, basic visualization (trend graphs and direct interaction using interactive variables), data logging and experimental session's control. A RLAB (Remote LABORatory) system is defined using a formal specification (which is LEDML, based on XML).

The RELATED structure is based on the module paradigm that leads to a structured development strategy. This way, laboratories are developed in a more rational way, reducing development times and optimizing human resources. With RELATED there is no need to start from scratch in the process of remote laboratory development.

The main component in RELATED is an experiment, which is defined on the laboratory XML specification. Experiments are composed of modules and views.

Modules are developed by the lab designer in order to provide local access to laboratory equipment. These modules, which are run-able entities, are started by the RELATED facilities in order to get/set data from/to the laboratory equipment. This data will be sent over the Internet to the RELATED client too.

The other basic entity of a RELATED laboratory (RLAB) is the view. A view provides a Graphical User Interface (GUI) to the final user. These views use data from modules to update the experiment visualization. It is possible the updating of the modules values from the view entity.

Java is used to develop modules and views. In the case of views there are several utilities that simplify the programming process. Easy Java Simulations (EJS) [11] is a free authoring tool that helps non-programmers to create interactive simulations and GUI in Java. GLG Toolkit [12] is another option to simplify the development of the view modules.

Once every module is developed, the next step is to prepare the XML file that is the definition of the laboratory. There are tags for experiments, views and modules. Inside a `<module>` tag there should be an `<implementation>` tag that specifies the coded entity of the module.

Figure 1 show an example of the XML laboratory definition where it can be seen how a module is defined. The

```
<module name="PIV_MODULE">
  <var name="current" type="double" initial="0" max="3" min="0" units="I">Current applied for
  electromagnetic field</var>
  <var name="position_sp" type="double" initial="0" max="3" min="0" units="mm">Position setpoint
  measured from MAGLEV</var>
  <var name="position" type="double" initial="0" max="3" min="0" units="mm">Ball position</var>
  <var name="SP_OffsetPosition" type="double" initial="0" max="9" min="-5" units="mm">Position
  setpoint sent to levitator</var>
  <var name="Kff_b" type="double" initial="142.9291" max="10000" min="-10000" units="A/m">PIV
  Controller parameter for ball position</var>
  <var name="Kp_b" type="double" initial="-229.0363" max="10000" min="-10000" units="A/m">PIV
  Controller parameter for ball position</var>
  <var name="Ki_b" type="double" initial="-192.3205" max="10000" min="-10000"
  units="A/s/m">PIV Controller parameter for ball position</var>
  <var name="Kv_b" type="double" initial="-3.7808" max="10000" min="-10000" units="A/s/m">PIV
  Controller parameter for ball position</var>
  <var name="Kp_c" type="double" initial="182.875" max="10000" min="-10000" units="V/A">PI
  Controller parameter for current</var>
  <var name="Ki_c" type="double" initial="24801.5625" max="100000" min="-100000"
  units="V/s/A">PI Controller parameter for current</var>
  <implementation type="JAVA" jarfile="...examples/MAGLEV/code/MAGLEVCientJavaApplication.jar"
  classname="es.uned.sec.rlab.modules.maglev.MaglevPIVModule">PIV Feedforward Controller: Ball
  position</implementation>
</module>
```

Figure 1. XML example

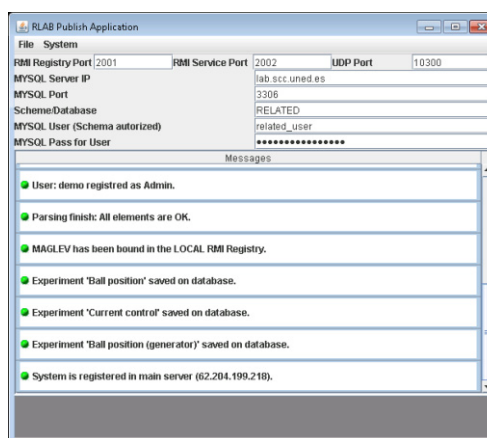


Figure 2. RLAB Publish Application

`<var>` tag defines the laboratory variables that can be modified in the RELATED Experiment Control Panel.

Once the XML file is ready, the last step is the publishing of the laboratory. For doing that a RLAB Publish Application is provided. This application parses the XML file then uploads to RELATED Server the files needed for running the lab, and then, the application keeps running on the lab machine to provide access to lab equipment. Figure 2 shows the publish application.

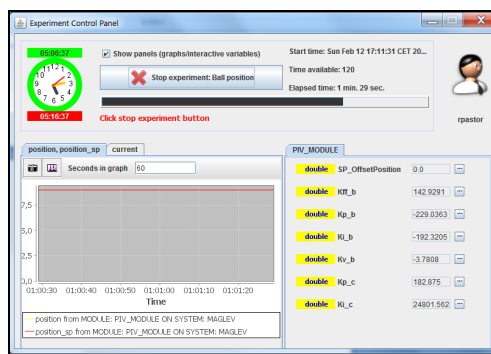


Figure 3 Experiment Control Panel

The Experiment Control Panel is the place where most of the activity of the remote lab takes place. To get this panel is necessary to login in the RELATED Server, select one of the experiments available for the user and then, login into the experiment.

Not all of the experiments registered on the RELATED Server are available to every user. When the student logs into the experiment, he/she reserves a time slot, this slot time is assigned to avoid multiples concurrent users and can be set using the booking system provided for RELATED so a start and a finish date is assigned to the running experiment and the user. The experiment control panel shows a clock to indicate to the student the time remaining to do the experiment.

Also RELATED log into the server all the events done during the experimental session this way, a concrete experimental session can be perfectly reproduced in future. This is specially useful in a learning environment in which the experimental sessions must be evaluated. As a counterpart, all these facilities lead to high server loads.

In a environment with lots of laboratories and lots of students, could be difficult to manage such high quantity of information so cloud technology could be used to enhance RELATED, optimizing university resources.

### III. REMOTE LABORATORIES AS A SERVICE

UNED is working on harnessing cloud technology to manage its technological infrastructure, so that fault-tolerance, scalability, and low power consumption are achieved. In order to provide the before mentioned benefits, a cloud based architecture is under development at UNED. Similarly to [13], a cloud based architecture can be implemented to improve on the scalability of RELATED. This architecture will rely on cloud and virtualization principles to provide efficient and scalable use of RELATED.

This architecture is presented in Figure 4, and has the following components:

- RLab component servers: One for each laboratory. Provides access to the lab it is connected to (as described in [9]).

- Data base: Keeps information on the labs, and their available time slots.

- RLab control web server: Works as a reference server, grants access to the labs based on permissions (as described in [9]).

- Load balancer: Balances the incoming connections from users between the servers available at each moment. An example of load balancer could be Nginx [14].

- Monitor: Performs the monitoring of the servers. It checks several parameters such as their CPU or memory usage. An example of monitor could be Ganglia [15].

- Virtual Infrastructure Manager (VIM): Performs the deployment of virtual machines (VMs) running the web server. It adapts the infrastructure (by means of deploying VMs in a public cloud provider such as Amazon Elastic Compute Cloud, EC2 [16]) in order to meet the current workload. An example of VIM is OpenNebula [6].

In order to provide scalability, a sharding architecture [15] can be implemented for the database, in which it can be split into a number of databases. Each database would hold a subset of the data (the shards), where shards can be replicated to provide fault-tolerance and scalability. Besides, concerning the load balancer, load monitor and the VIM, other machines could be set to back them up in the case of failures. Even more, data in our local premises can be de-duplicated [18] so that no data are lost in the case of local failures.

On the other hand, in order to provide efficient quality of service (QoS), a load forecasting technique could be implemented, similarly to [13]. This way, resources could be allocated based on the expected workload we plan to receive so that the system is adapted to it. This way, the system could be made of as less machines as possible (thus saving power), but at the same time it could be providing efficient service to its users – thus providing green computing.

### IV. CONCLUSIONS AND FUTURE WORK

Thanks to cloud computing, a number of benefits can be obtained with regard to the management of computing infrastructures, such as lower power consumption and improved system utilization. This paper

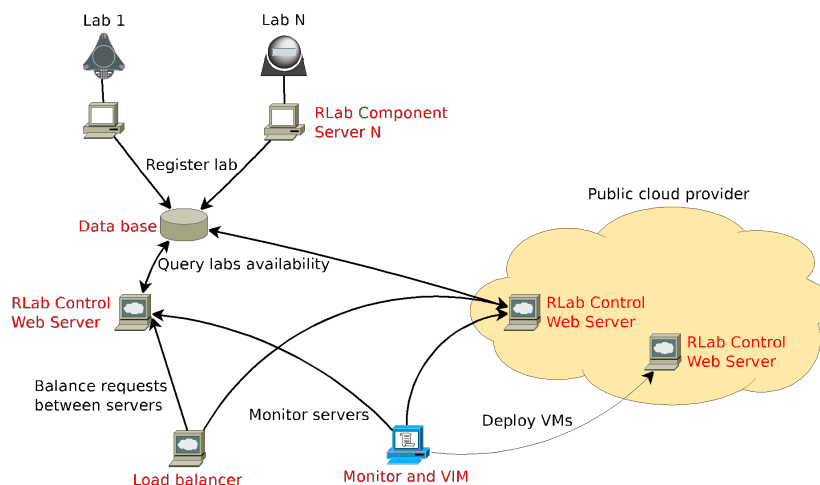


Figure 4. Proposed Architecture

presents the efforts carried out at UNED, the largest university of Spain, aimed at extending a remote laboratories technology with cloud principles. This remote laboratory technology (called RELATED), has been in use in our university for several years with satisfactory results. The current paper explains the developments being made in our university in order to extend RELATED with cloud technologies in order to allow it handle large workloads and minimize its power consumption. Among our future work, a full implementation of the architecture presented in this paper is one of the main research lines.

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