

# Remote laboratory prototype for automation of industrial processes and communications tests

## Prototipo de laboratorio remoto para prácticas de automatización de procesos y comunicaciones industriales

Sebastián Castrillón-Ospina <sup>a</sup>, Luz Inés Hincapie <sup>b</sup> & Germán Zapata-Madrigal <sup>c</sup>

<sup>a</sup> Facultad de Minas, Universidad Nacional de Colombia, Colombia. [scastril0@unal.edu.co](mailto:scastril0@unal.edu.co)

<sup>b</sup> Facultad de Minas, Universidad Nacional de Colombia, Colombia. [lhincap@unal.edu.co](mailto:lhincap@unal.edu.co)

<sup>c</sup> Facultad de Minas, Universidad Nacional de Colombia, Colombia. [gzapata@unal.edu.co](mailto:gzapata@unal.edu.co)

Received: December 5th, 2012. Received in revised form: February 20th, 2014. Accepted: May 12th, 2014.

### Abstract

This paper presents the initial phase of the approach and implementation of a prototype of virtual infrastructure for teaching and lab development in the areas of Industrial Automation and Industrial Communications. The proposed prototype allows remote lab practice using: internet, VMware virtualization and management through Netlab. It allows easy and permanent access to the automation software and hardware necessary for an adequate student experience with real devices.

*Keywords:* manuscript formatting; Virtualization; Cloud Computing; Virtual machines; Remote laboratory; Web platform; Logical Programmable Controller; Industrial Ethernet; Industrial Communications.

### Resumen

En este artículo presenta la fase inicial del planteamiento e implementación de un prototipo de infraestructura virtual para la enseñanza y el desarrollo de laboratorios en las áreas de Automatización Industrial y Comunicaciones Industriales. El prototipo propuesto permite que las prácticas sean desarrolladas remotamente mediante el uso de Internet, la virtualización de VMware y la gestión a través de NetLab, lo que permite un acceso fácil y permanente al software de automatización y los materiales necesarios para una adecuada experiencia de los estudiantes con los dispositivos reales.

*Palabras clave:* Virtualización; Cloud Computing; Máquinas virtuales; Laboratorio remoto; Plataforma Web; PLC; Ethernet industrial; Comunicaciones industriales.

### 1. Introduction

The introduction of virtualization technologies and Cloud Computing has permitted a considerable cost reduction associated with the implementation and maintenance of IT systems. The adoption of these new technologies can be seen in enriched collaboration environments and in improved process agility. Their adoption is finally translated into considerable productivity increases.

Internet and Cloud Computing have been integrated into education processes of multiple institutions. However, some knowledge areas have presented some degree of resistance to the integration of these new technologies within the learning processes. Laboratories with electrical machines and automation are used as examples of subject areas where physical contact with the laboratory resources is almost indispensable.

Given the potential of the Internet and the different virtualization technologies in existence, it is appropriate to

perform a study that enables the integration of these new technologies into laboratories that contain physical resource restrictions and that normally require a physical presence for access to them.

In this work, the structure of a remote laboratory is presented as a support tool for the development of the practical component of industrial automation courses offered to undergraduates in Electrical, Control, and Mechanical Engineering at the Universidad Nacional de Colombia – Sede Medellín (National University of Colombia – Medellín Campus).

The article is structured in the following way: In section 2, a review of the state of the art and related works is performed. In section 3, the theoretical foundation of virtualization and Cloud Computing technologies is presented. Then, in section 4, the description of the proposed methodology and the architecture for development of a remote laboratory, applicable to industrial automation teaching, is presented. Last, in section 5, the conclusions of

the work are presented, and future works are defined.

## 2. State of the art and related works

Virtualization and Cloud Computing concepts are not new. In 1964, IBM developed the concept of virtualization in their IBM/S360 system. That system gave rise to the term “family architecture” and consisted of six computers that all could use the same software and the same peripherals. Using terminals connected to a server through a telephone line, remote computing came into existence. The term Cloud Computing was introduced in the 1980s under the concept of Grid Computing, which is emphasized in virtual servers. Later, it was adopted by large-scale Internet providers such as Google, Amazon AWS, Microsoft, and others that built their own infrastructure [1], [2].

Virtualization and Cloud Computing have evolved over time and they have positively impacted different areas such as the industrial and academic sectors.

In the managerial sector, the virtualization of servers and storage has gained a prominent position. Other trends such as Web application virtualization, email, and calendars have gradually found their place. Also there are standout Infrastructures virtualization and management, the virtualization of jobs and the management and automation of virtual environments, among others.

The virtual machines and applications development such as VirtualBox, “VMware”, “Qemu”, “Virtual PC”, “Google App Engine”, and “Virtual Application Networks” and others, have contributed to the continuous usage of virtualization and Cloud Computing technologies. They provide multiple options and alternatives for applications according to requirements of a specific sector or industry.

“VirtualBox”, “VMware”, “Qemu”, and “Virtual PC” are operating systems virtualization tools. These types of tools enable the creation of a virtual computer or PC within a real one to install multiple operating systems that execute independently within real operating system [3], [4].

“Google App Engine” is a platform that allows the development and execution of Web applications using Google’s infrastructure [5].

“Virtual Application Networks” is a Hewlett Packard Cloud functionality that provides a virtual network vision (abstracted from the physical equipment) that transforms a physical enterprise network into a programmable, multiuser network that is able to recognize applications [6].

Some cloud infrastructure and virtualization solutions including vCloud, vsphere, and vCenter Operation Management Suite, and others also stand out. These solutions are owned by the well-known company VMware Inc. [7].

In the academic environment, the authors of [8] refer to the design and implementation of a remote laboratory to teach Control and Automation courses at the Universidad Miguel Hernández de España (University Miguel Hernandez in Spain). This work details the hardware and software architecture of this system and introduces the Web application developed to enable access to different laboratory services.

Similar applications to the proposed one in [8] are described in [9], [10] and [11]. ZUBÍA, J., DE VELASCO refer to the remote lab controlled from the Internet (WebLab) and describes its definition, technological advantages, and common implementation strategies. ZERPA, S., GIMÉNEZ, D. also cover remote labs over the Internet. They describe a remote laboratory that facilitates the development of the practical component of automation and process control courses for the students. From this work, the hardware– software system is used to perform variable monitoring and control of an industrial process prototype located in the Industrial Automation Laboratory in the Electronic Engineering Department at the Universidad Politécnica “Antonio José de Sucre”, UNEXPO, Barquisimeto, Venezuela (“Antonio José de Sucre” Polytechnic University ). The purpose was to implement a Modbus/TCP/IP network for the virtual practice session development using a Programmable Logic Controller or PLC.

Other interesting studies regard the implementation of virtual labs for teaching automation courses and similar courses such as [12] and [13]. In general terms, HERÍAS, M., MORENO, J. describes the role that Information and Communication Technologies have within teaching processes in different subjects, such as Information Technology and Automation. This study provides the description of multiple resources based on the Internet that can be used to support learning.

DANILLES, S., CUSTODIO A. show the design of a virtual environment for the remote programming of a Programmable Logic Controller (PLC) for the development of remote engineering exercises. The main motivation of this project was the large number of enrolled students in Electronics courses, therefore, an alternative to physical presence in the classroom was created for the students to conduct different practical exercises, thereby facilitating their execution.

## 3. Theoretical Framework

### 3.1. Virtualization and Cloud Computing: definition

Various definitions have been assigned to the terms “virtualization” and “Cloud Computing”. It is tended in some instances to associate the same meaning with both terms. However, it is important to note that both terms have different meanings, though they are related.

The term virtualization broadly describes the separation of a resource or request for a service from the underlying physical delivery of that service [15]. Virtualization divides physical

hardware and operating system apart so that to provide higher utilization of IT resources and flexibility [16]. SMITH, J, NAIR R, define virtualization how the most significant progress since the microprocessor introduction, in providing information and business secure systems.

LASSO, G. defines Cloud Computing as “a model that provides on-demand access to a shared and configurable set of IT resources (networks, servers, storage, applications and

others) in a convenient way and that can be quickly served with a resources provider minimal effort ”.

### 3.2. Types of Virtualization

Different types of virtualization have been established. In general, three broad types of virtualization can be distinguished: server virtualization, desktop virtualization, and data storage virtualization. Next, we present a brief description of these classifications and distinguish other types of virtualization within them.

#### 3.2.1. Server virtualization

The architecture of today's x86 servers allows them to run only one operating system at a time. Server virtualization unlocks the traditional one-to-one architecture of x86 servers by abstracting the operating system and applications from the physical hardware, enabling a more cost-efficient, agile and simplified server environment. Using server virtualization, multiple operating systems can run on a single physical server as virtual machines, each with access to the underlying server's computing resources. [20].

In operating system virtualization, there is a base operating system or host where virtualization software is installed. It is called a hypervisor and allows the installation of other operating systems that run on the main operating system. These operating systems are called guests and use a virtualization layer provided by the virtualization software (VMware Workstation, Virtual PC, Hyper – V, among others). In the case of hardware emulation, the virtualization software generates a software layer that emulates the hardware, that means, computer resources for the operation of the installed operating system work as if it was found in a single computer. Finally, in paravirtualization there is no hardware emulation. The hypervisor coordinates the access of guest operating system to the physical computer resources [19].

#### 3.2.2. Desktop virtualization

The architecture of today's x86 servers allows them to run only one operating system at a time. Server virtualization unlocks the traditional one-to-one architecture of x86 servers by abstracting the operating system and applications from the physical hardware, enabling a more cost-efficient, agile and simplified server environment. Using server virtualization, multiple operating systems can run on a single physical server as virtual machines, each with access to the underlying server's computing resources. [20].

#### 3.2.3. Netlab definition

NETLAB is a laboratory platform for using CISCO, VMware, and CompTIA academies. With this platform, teachers and students can remotely access the laboratory with real equipment in an easy management environment over the Internet.

#### 3.2.4. Benefits

- It enables the development of remote exercises. NETLAB Academy Edition allows the students to have additional time for their laboratory exercises and to make maximum use of laboratory equipment. NETLAB allows access to laboratory equipment twenty-four hours a day, seven days a week.
- It optimizes the laboratory time inside the classroom. It enables instructors to spend more time teaching and less time in laboratory equipment management.
- The laboratory resources can be shared with other universities. Because access to Netlab is over the Internet resources can be shared with other universities that need them.
- Students can work in groups. Students can organize themselves in workgroups to develop exercises inside and outside of the classroom without the need for all group members to be in the same physical location.
- System activity log. The system saves all the actions of the student using the equipment during the laboratory activity, which enables the instructor to evaluate the performance of the student in the laboratory and to provide feedback to the student.
- Grants scheduled access to laboratory. A reservation is required for each individual's access to the laboratory. Thus, the students schedule when they are going to develop the exercises according to their time availability, and instructors can reserve the laboratory for class times with demonstrations using real equipment.

## 4. Theoretical Framework

To get true remote student access and local connectivity (inter-university) we have an infrastructure that allows access by means of a WEB service with a public domain <http://netlab.unalmed.edu.co>. This URL will give the access to the Netlab graphic interface, which works like a bridge and manager for equipment access and for the automation and control software.

### 4.1. Virtualization and Cloud Computing: definition

Netlab allows physical laboratory space reservation management, which is a pod laboratory interaction via WEB, we make reference to laboratory pod as a devices group that are used by one student or students group in a specific reservation. Netlab scalability is one of its characteristics as it allows the user to easily add new laboratory devices when they are acquired in a new pod, then they can be used by multiple students in a simultaneous way within different reservations.

Netlab works as a proxy between connections, creating a bridge between the clients and the laboratory virtual machines. It allows access to be simplified because only a web browser with a Java plugin is required.

The control switch enables the connections between the Netlab server, the laboratory topology computers, and the

automation elements in use.

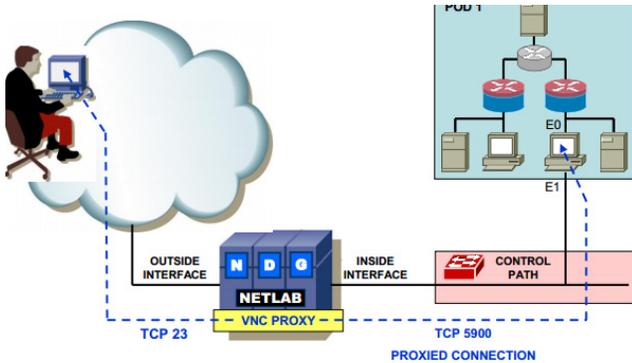


Figure 1: Netlab architecture

Virtual machines are provided by a dedicated virtualization server. Using a VMware ESXi 4.1 Hypervisor, the virtual machines have access to devices using an Ethernet, a USB, or a serial port, which enables access and configuration of different series of the implemented automation equipment.

#### 4.2. Pod for automation

Laboratory topology design allows a model of different industrial cases and with different manufacturers to be made. For that an industrial communication network with Rockwell and Siemens equipment is planned, each one with their communications ports that allow communication with protocols as well as Profinet and Ethernet.

Based on Fig. 2 each one of its component is described:

- 2 virtual machines where all required programs to develop the courses activities, as well as configuration, monitoring and simulation are installed. Netlab has the ability to come back to the default state of each virtual machine at the end of the reservation.
- 2 web cameras that allow the change of the equipment leds to be observed.
- 2 Siemens s7-200 PLC with Factory Ethernet port.

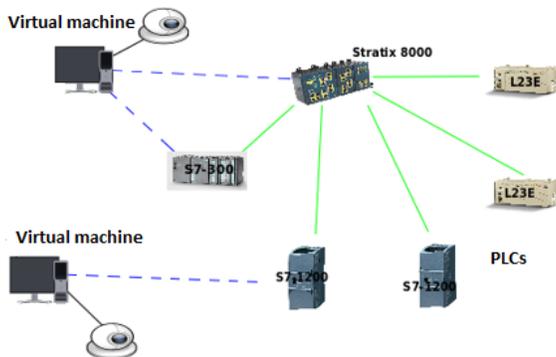


Figure 2: Automation laboratory model

- 1 Siemens S7-300 PLC with Ethernet module.
- 2 L23E-1769 Rockwell PLC with Ethernet port.

#### 4.2.1. Input and Output

It is necessary for individuals who interact with the system to be able to activate and deactivate the inputs and outputs of each one of PLCs that are permitted by the process. This can be done with OPC technology using Matrikon software from Matrikon Inc. or KepserverEx software from Kepware. The software also allow the activation and deactivation of inputs and outputs virtually. This can be physically observed in the equipment using Web cameras or in Manufacturing Execution System MES.

#### 4.3. Case study

The research Group Teleinformatics and Teleautomatic of Universidad Nacional de Colombia – Sede Medellín has been studying industrial communications; therefore, it is appropriate to propose a case study where the available communication media are integrated with Siemens S7 controllers and Rockwell L23E-1769 controllers. This case covers the laboratory topology necessary to simulate a Manufacturing Execution System (MES) with a topology that contains Industrial Ethernet communication protocols.

The simulated manufacturing lines consist in beer bottling and packaging in ten-unit boxes. This simulation is of the production of 1 bottle every 2 seconds in the inlet line (Bottling) and 3 boxes per minute in the outlet line (Packaging). In addition, failures in the production line will be simulated. Good and bad bottles and boxes will be counted. The SIEMENS equipment include a Bottling controller (S7-1200), a Packaging controller (S7-1200), and Master OPC (S7-300). When using the Rockwell equipment, one controller (L23E-1769 QB1B) was used for Bottling and Packaging, and another controller served as the Master OPC (L23E-1769 QB1B).

Communication between PLCs S7-1200 was by the TCP protocol, and communication between PLC S7-122 and PLC S7-300 was by the S7 protocol (TCP based, SIEMENS proprietary protocol). When using Rockwell equipment, communication between two PLCs L23E-1769 was performed in two ways: the first one used Produced-Consumed tags, and the second one used Message blocks.

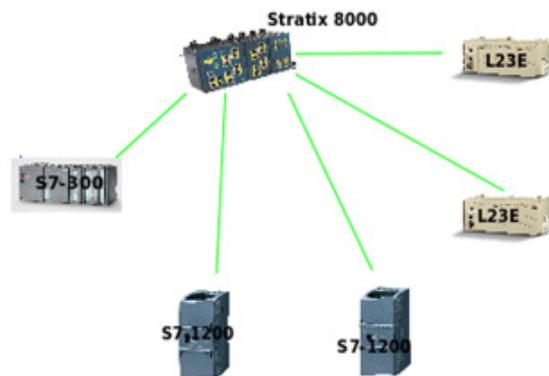


Figure 3: Automation laboratory model

### 4.3.1. Implemented software

Implementation of the proposed case study required the use of different applications to program the PLCs, such as TIA PORTAL PROFESIONAL SP2 and the Step 7 V5.5, both for the Siemens equipment, and Rslogix 5000 and RSLinx Lite for the Rockwell PLCs. To implement the manufacturing execution system, two programs were used. These programs are Manufacturing Execution System V4.0 made by Wonderware and Ignition made by Inductive Automation, DEMO version.

When communicating between different control equipment and MES, OPC technology was required, KepserverEx v5.0, DEMO version was used, made by Kepware.

The university has education agreements and full licenses of the implemented software by means of complete versions.

## 5. Conclusions and future work

- Netlab scalability and flexibility allow the implementation of many other laboratory topologies to control and automation systems of many manufacturer cases and electric systems.
- Actually method consolidation is being worked on that will be used to manage the system inputs and outputs, both analog and digital, that allows new characteristics to this Pod or new Pod to be implemented, that be developed and appropriate for other case studies.
- With this work, networking concepts, Cloud Computing, and industrial communications were integrated to achieve 24-hour availability of an industrial automation laboratory from any location.

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**S. C. Castrillón-Ospina**, received the Bs. Eng in Control Engineering in 2008, from the Universidad Nacional de Colombia. Medellin, Colombia. MS student in telecommunication engineer at Univesidad de Antioquia, he work as a Research Engineer for the Investigation Group in Teleinformatic and Teleautomation of the Universidad Nacional de Colombia. Since 2008 he work for telecommunication research and consulting companies within the telecommunication sector. His research interests include: simulation and modeling of protocols and telecommunication systems; virtualization networks models; and industrial protocols for automation.

**L.I. Hincapié-Mesa**, received the Bs.Eng in Control Engineering from the Universidad Nacional de Colombia - Campus Medellin in 2008. Sp Degree in Teleinformatic: Data Networks and Distributed Systems from the Universidad EAFIT - Campus Medellin, Colombia in 2011. From 2008 to 2012, She worked as a Research Engineer and Project Management support for the Investigation Group in Teleinformatic and Teleautomation of the Universidad Nacional de Colombia. Currently, she works in the areas of: Management of Information Technology Projects, Telecommunications Infrastructure management and operational support . Her main research interests include: Next Generation Networks (NGN), networking security, industrial communications, network management tools and Cloud Computing applications.

**G.D. Zapata**: Received the Bs. Eng in electrical engineering from the Universidad Nacional de Colombia. Medellin, Colombia in 1991, MS degreed in Automatic from the Universidad del Valle in 2004 and the PhD degreed in applied science from the Universidad de los Andes in 2012. He work as associated professor at Universidad Nacional since 1992 and is currently the group director for the Investigation Group in Teleinformatic and Teleautomation of the Universidad Nacional de Colombia. His research areas are: Industrial Automation, Automation of Power Systems, Discrete Event Systems, monitoring systems, intelligent production systems.