# A Cloud-Based Architecture for Robotics Virtual Laboratories

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**Abstract.** Nowadays, robotics plays a very important role in the improvement of the quality of life, because it helps to automate tasks from several fields such as services, production, housing, and education. However, robotics projects in Higher Education require a big investment. To save resources, a big group of students must work on the same project. This fact does not allow students to develop their abilities because they are not involved in all the stages of the project. Thanks to the advance of technology, learning trends such as virtual laboratories have arisen. These laboratories bring advantages such as flexibility, scalability, collaborative tools, and better communication among students. In this work, we propose a three-layer architecture for virtual laboratories which uses basic principles of Cloud computing and virtualization. This platform was used for the development of robotics projects within the Agrarian University of Ecuador. The platform has proven to be creative, modern, and accessible for universities.

**Keywords:** Robotics · Virtual laboratories · Architecture · Simulators

## 1 Introduction

Higher education institutions have been contributing to the meaningful learning approach. In this approach, teachers must connect previous knowledge with new knowledge, thus achieving significant learning where all knowledge is connected. It is important to emphasize that this kind of learning allows students to increase their self-esteem and motivation to learn more. To achieve this goal, materials and resources contribute greatly to produce this type of learning [1].

Nowadays, robotics plays a very important role in the improvement of the quality of life, because it helps to automate tasks from several fields such as services, production, housing, and education. Robotics projects in Higher Education require a big investment. To save resources, a big group of students must work on the same project. This fact does not allow students to develop their abilities because they are not


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involved in all the stages of the project. Thanks to the advance of technology, learning trends such as virtual laboratories [2] have arisen. This kind of laboratories has been used for years in countries like Spain. Hence, this country can contribute to the creation of virtual and remote laboratories for science and engineering education [3]. In these laboratories, a computer simulation can be carried out through an Internet communication infrastructure. This software and hardware infrastructure allows users to remotely control real or simulated devices, thus allowing students to perform their practices without being physically present in the laboratory. At the same time, these laboratories bring advantages such as flexibility, scalability, collaborative tools, and better communication among students. Finally, it should be mentioned that these laboratories foster the development of multidisciplinary research groups.

Although virtual laboratories have been widely used in other countries [4], in Ecuador these laboratories are used in disciplines [5, 6] other than robotics. In this sense, the Agrarian University of Ecuador as an Institution of Higher Education seeks to contribute to the scientific and professional community. Therefore, it implemented a virtual laboratory [7] for designing robotic prototypes that satisfy a specific need considering the parameters proposed in class. Thanks to these practices, students obtain valuable tools that will allow them to integrate current knowledge with previous knowledge, thus achieving pedagogical effectiveness, which enables students to develop practical and multidisciplinary skills.

## 2 Related Works

ICT (Information and Communication Technology) provides education with a tool that enables teachers and students to work collaboratively. The use of software for virtual simulations encourages students to interact with new technologies by improving the teaching-learning process in different fields such as robotics [8]. Furthermore, this software allows students to develop critical thinking to take advantage of current technologies including distributed systems in areas such as chemistry, physics and robotics. At the UNED (University of Distance Education) in Spain, the use of practical laboratories is a key factor in engineering education. Considering the approach followed by this university, i.e. the lack of physical interactions among teachers and students, this university implemented a system for managing remote virtual laboratories [9] to improve the way in which practical tasks are performed. This system provides each student a virtualization-based virtual laboratory that can be accessed through the Internet.

Lab4CE [10] is a remote virtual laboratory that adopts a modular, flexible and distributed architecture that integrates a set of tools and services focused on teachers and students. On the other hand, NetLab [11] is a remote laboratory developed at the University of South Australia that improves the flexibility of access to students and increases their learning experience. The UOC (Open University of Catalonia) implemented a structure of virtual laboratories [12] that integrates technological, strategic and academic resources in a virtual learning environment considering the features that are important for the development of practical activities.

In Ecuador, there are industrial, chemical and physical remote laboratories that are using a methodology [6] based on working with virtual laboratories. This methodology arose to improve the sharing of research results with potential users. On the other hand, there are some initiatives in schools and colleges for the creation of virtual laboratories. For instance, the Educational Unit Lady of the Swan has a physic virtual laboratory [13] where children can perform different academic activities.

There are local and remote virtual laboratories. On the one hand, in local virtual laboratories, resources are executed in a server from which academic resources are downloaded to a personal computer. In this scenario, the virtual laboratory can be only one computer in which there is no communication with the teacher. Even, in this kind of laboratories, students can perform their tasks without Internet access. The main advantage of local virtual laboratories is that students can directly interact with all resources. However, its main disadvantage is that it requires many resources, a physical space, maintenance, and the physical presence of students and teachers. On the other hand, in remote virtual laboratories [9], a remote server executes all different processes. In this scenario, students carry out their practices in a collaborative way, where teachers and other students are involved. Furthermore, although these laboratories do not require a great investment, students cannot interact with real equipment [14]. These laboratories cannot be applied to certain experiments that require specific resources and organization. Furthermore, sometimes the presence of the teacher is required. Another disadvantage is that students do not manipulate real equipment. However, some advantages of remote laboratories are [15] the possibility of performing practices from remote places, the access to different equipment without time restrictions, observation of sessions by many users, reduction of the costs associated with real practical laboratories, simulated processes by means of Software, as well as the possibility of acquiring a better understanding of the hardware. Furthermore, remote laboratories allow disable people to have access to these resources.

Table 1 summarizes the classification of local experimental environments. Real laboratories have physical systems with which people have interaction. These systems allow obtaining real data, however, they require space and maintenance. Regarding local virtual laboratories, these ones have simulated systems. The main advantage of virtual laboratories is that the investment costs are lower than real experimental environments.

**Table 1.** Classification of local experimental environments.

| Type | Description |
|---|---|
| Real | Laboratories with real physical systems |
| Virtual | Laboratories with simulated systems |

Table 2 summarizes the classification of remote experimental environments. Thanks to remote laboratories, students can perform experiments at the most convenient time for them, thus allowing them to make an efficient use of their time. Furthermore, this kind of systems allows students to perform a wide variety of practices. In remote environments, students can work on software-simulated systems, which make them an ideal tool for experimentation.

**Table 2.** Classification of remote experimental environments.

| Type | Description |
|---|---|
| Real | Teleoperation of a real systems |
| Virtual | Remote laboratories with simulated systems |

# 3 Open-Source Tools

## 3.1 Open-Source Cloud-Based Platforms

There are cloud-based remote laboratories for mechatronics [16] that facilitate the access to a large amount of computing and storage resources. These platforms transform an informatic infrastructure into a private or hybrid cloud [17]. In this work, two open-source platforms were analyzed namely, OpenNebula [18] and Yellow Circle. The first platform allows managing heterogeneous infrastructures of distributed data sources which are integrated at different functionality levels through KVM and VMware [19]. Figure 1 presents the general architecture of these platforms. Such architecture is composed of several interfaces that enable the interaction and management of physical and virtual resources.

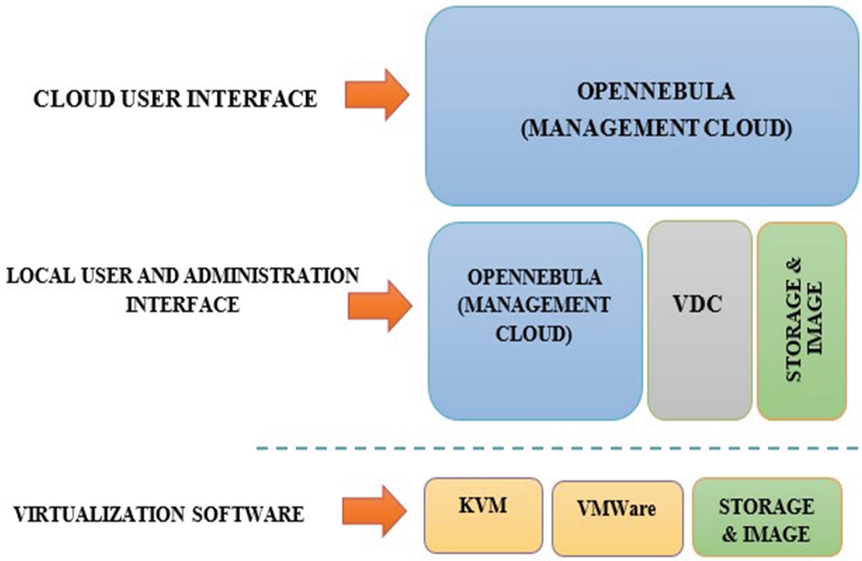


**Fig. 1.** OpenNebula architecture.

The user interface allows the management of virtual machines (VM), networks and virtual images. There are two kinds of interfaces: end-user interfaces and expert users' management interface. The system interface provides a general perspective of all functionalities given by OpenNebula. Some of these functionalities are: infrastructure customization, and the management of resources such as virtual machines, networks, virtual images, users, nodes and clusters [18].

On the other hand, Yellow Circle is an IT-based platform that provides Cloud computing features for creating learning environments for students and for implementing real-world TI-based infrastructures without having to worry about the associated costs. With this platform, students can create, manage and customize their own virtual datacenter. The number of network jumps between the end user and the Cloud is a key element to evaluate the Cloud performance [20]. Yellow circle generates 19 jumps between the Cloud and the end user, which indicates that this platform has a good performance.

### 3.2 Free Software Tools for Robotics

Software and hardware play an important role for constructing robots. Hence, it is important to address different requirements of the application which depend on several limitations such as performance and soundness [21]. Generally, the software system of the robot is concurrent, distributed, embedded, real-time and data-intensive. However, due to the increasing complexity of robotics applications, the modularity, reusing, and compatibility are also considered important factors at the moment of selecting the software [22]. In this work, the open-source software for robotics V-REP [22], ROBOTICS-STUDIO [23, 24] and GAZEBO [25] were analyzed. Table 3 presents a general description of the features provided by software above mentioned.

**Table 3.** Features of open-source software for robotics.

| Software | Operating system | License | Programming language | Calculation modules |
|---|---|---|---|---|
| V-REP | Windows, Linux, MacOS | Commercial license, GNU GPL | C/C++, Python, Java, MATLAB, Octave, Urbi | Kinematics module, dynamics module, collision detection module, mesh-mesh distance calculation module, path/motion planning module |
| ROBOTICS STUDIO | Windows | CTP | .NET platform, VBasic, C/C++ | Visual Programming Language, RDS 3D simulation environment, the Kinect sensor |
| GAZEBO | Linux | Apache 2.0 | Python | ROS Integration, world Modelling, Robot Model Modifications, Programmatic Control |

## 4 Case Study

This section describes a case study that was developed at the Agrarian University of Ecuador, more specifically, in the Computer Science degree. This process involved 50 students from the course Introduction to the Robotics.

Nowadays, there is no a robotics laboratory in this university. This fact makes it difficult the teaching-learning process as students do not have the correct tools to perform the corresponding robotics practices, which demands a great investment for acquiring the required resources. Based on these facts, in this work, we propose a free architecture for implementing robotics virtual laboratories that help students create and test their own robotics design in a cheap and simple way.

From the open-source software for robotics analyzed in the previous section, the Yellow circle platform was selected for implementing the virtual laboratory proposed in this work. The main reason why Yellow circle was selected is that it generates a smaller number of network jumps than OpenNebula, which generates around 30 network jumps. Therefore, a private environment was created to have physical nodes [26] with a wide set of infrastructure services, storage options, 25 operating systems and networks. Among the operating systems and software supported by Yellow Circle are Windows Server, Microsoft SQL Server, Red Hat Enterprise, Linux, Oracle Enterprise, Java Application Server, to mention but a few.

The virtual laboratory implementation was performed in public Cloud environment by Yellow circle. This environment consists of 50 virtual machines with Windows 7. The hardware specification of all virtual machines is a VCPU-4, 8 Gb RAM, 35 Gb storage, and the necessary software for carrying out the robotics practices was based on V-REP [27].

Students can access to the Cloud-based robotics simulator from anywhere with the corresponding user and password for authentication. Once students have logged into the system, they can perform configured practices or create new practices to work in collaboration with other students. Figure 2 shows the Cloud-based architecture for robotics virtual laboratories proposed in this work. This architecture is composed of three layers namely virtual classroom (Web application), Virtual laboratory and the Yellowcress-based technology infrastructure.

The virtual classroom promotes the e-learning process as well as the teacher-student interactions. In this layer, tasks, practice guidelines, and partial and final evaluations are created. Furthermore, it is possible to register all students' activities. Students can access the system from anywhere by using their corresponding username and password. The virtual classroom is related to the virtual laboratory, which represents the students' working area. The virtual laboratory is composed of virtual machines with the software for robotics V-REP. The technological infrastructure of Yellow circle learning platform provides resources such as router, networks, servers, firewalls and load balancers to design virtual laboratories. This environment contributes to the development of students' skills. Figure 3 presents the virtual laboratory with a network where students perform their robotics practices.

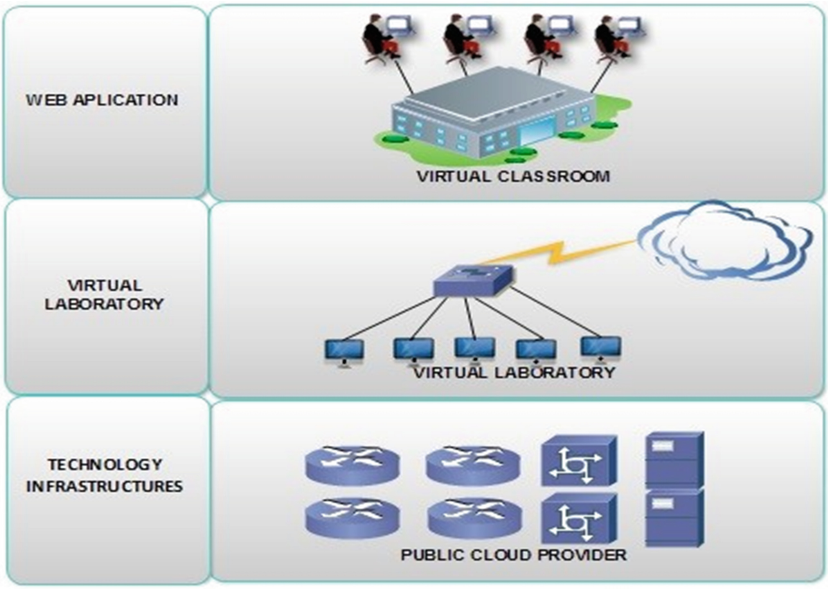


**Fig. 2.** Technological architecture proposed.

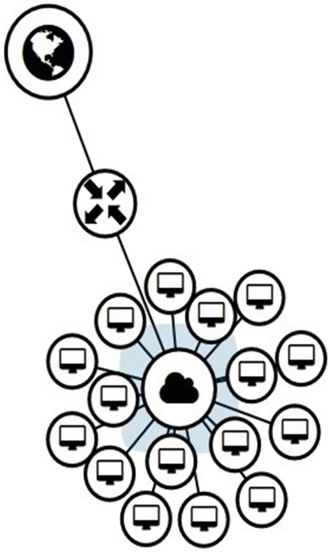

**Fig. 3.** Virtual laboratory.

### 4.1 Tests

To test the architecture proposed, a practice that involves a line follower robot was selected. The goal of this practice is that the robot has to follow a set of points. For this purpose, the following parameters were established: (1) the work environment must be limited by walls, i.e., it can be a room with chairs, tables, people or any other object that represent an obstacle; (2) the surface must be completely flat.

The simulated robot had to correctly implement all instructions to follow a set of established points. With regards to the movement, the robot can move forward and backward. Also, it was necessary to define the speed and the proper orientation for each route point. In addition, another simulation was performed by using a robot whose movement was like a person. After completing the simulation, students carried out an activity related to this practice both individually and in groups. Finally, they generated a set of reports and technical manual through the virtual laboratory.

### 4.2 Case Study Recommendations

It is suggested to perform the route planning tasks using the V-REP module (route generation engine) to establish the initial and final position. Another alternative is the use of the Braitenberg algorithm. For the second scenario, it is suggested to use a script to establish the movements of legs and arms along the route. In future works, more complex robotic designs that include more sensors will be implemented. Furthermore, we plan to include 3D printing for building prototype parts. According to this research, ROS [28] and V-REP [29] obtain better results than other robotics software. Therefore, ROS will be incorporated into the proposed architecture.

## 5 Results

In the last year, the robotics projects were developed by the students by using the architecture proposed in this work. This architecture motivates critical and creative thinking because V-REP provides a great variety of models that can be used in the project in an easy way. Furthermore, V-REP allows importing XML-based files without requiring knowledge and expertise about this format. Another feature of this software is that it allows using different sensors as well as a graphic visualization. On the other hand, this platform improves the group organization due to the students' participation was observed by teachers concluding that students learn to solve problems by teamwork. Finally, reports and technical manuals generated by students through the virtual laboratory complement the practical activities.

### 5.1 Evaluation

To evaluate the architecture here proposed, we carry out a survey by using the EVA criteria, in which students evaluated the practical experience and functionalities of V-REP, the virtual laboratory, and the virtual classroom. Table 4 shows all survey questions that were asked to the students that were involved in the case study.

Questions 2, 9, 10 and 11 are focused on measuring usability, question 12 measures interaction, and the rest measure the utility of the architecture. Students rated each question from 1 to 5, where 1 means strongly disagree, 2 disagree, 3 neutral, 4 agree and 5 strongly agree.

The results of the survey (questions 1 to 10) are shown in Fig. 4. Regarding usability, more than 50% of the students think that both the platform and the software V-REP are friendly and easy to use. According to the results obtained from question 12, 76% of the students think that the virtual laboratory makes it easy the interaction, design and programming of the robots. Regarding the availability provided by the virtual laboratory, 82% of the students think that this feature contributes to their academic training. This fact is confirmed by question 5, whose results indicate that the virtual laboratory is very useful. Finally, the time students spent on performing the robotics practice proposed was around 30 min, which is the average time for this kind of practices.

**Table 4.** Survey questions.

| No. | Question |
|---|---|
| Q1 | The environment and tools provided by the virtual laboratory facilitate the design and implementation of robots |
| Q2 | The working platform provided by the virtual laboratory is friendly |
| Q3 | The use of the virtual laboratory improves the learning process during the course Introduction to robotics |
| Q4 | The 24/7 availability of the virtual laboratory helps the academic training |
| Q5 | Indicate the utility of the virtual laboratory |
| Q6 | Indicate the access frequency to the virtual laboratory from the physical laboratory |
| Q7 | Indicate the access frequency to the virtual laboratory from the University |
| Q8 | Indicate the access frequency to the virtual laboratory from home |
| Q9 | The complexity degree of the virtual laboratory is low |
| Q10 | Do you think that the V-REP software is easy to use? |
| Q11 | The time you spent performing the practice was around 30 min |
| Q12 | The virtual laboratory provides features to interact with other students |
| Q13 | Which kind of Internet access do you have to perform the practices? |
| Q14 | Which kind of problems did you find performing the practices? |

Figure 5a shows that most students (80%) access to the platform using WIFI, whether from the university or from home (questions 6 and 7). This fact, in conjunction with the shown in Fig. 5b, denotes a decrease in speed access. However, when fiber optics is used, this problem is solved.

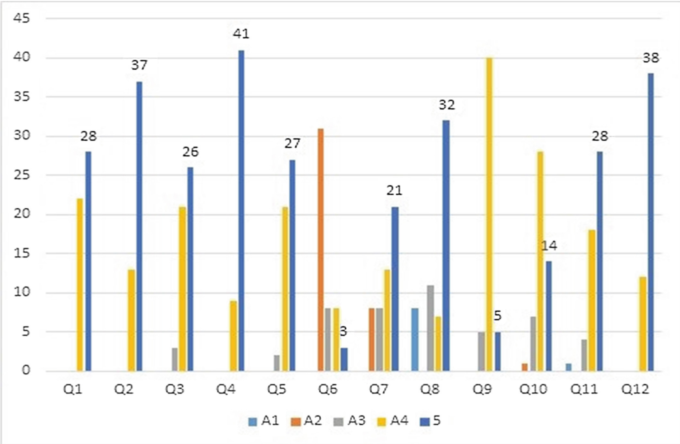


**Fig. 4.** Survey results.

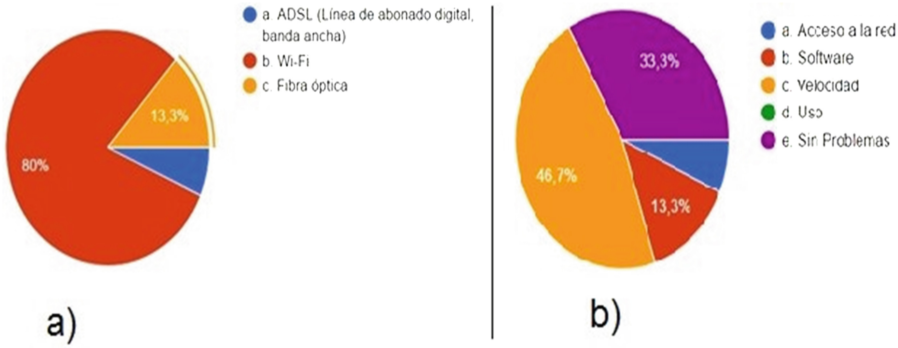


**Fig. 5.** A graphical representation of (a) types of access and (b) types of problems.

## 6 Conclusions

The three-layer architecture for virtual laboratories proposed in this work uses basic principles of Cloud computing and virtualization. Thanks to these technologies, the architecture provides features such as fault tolerance, scalability, among others. Therefore, we can conclude that this platform represents a creative, modern, and accessible option for universities, both distance and face-to-face. Using the teaching tools provided by the virtual classroom, the teacher can customize the robotics practices to be developed by the students, thus increasing the students' critical thinking as well as improving teamwork among students. One of the main advantages of this platform is the fact that virtual laboratories are always available. What is more, it has been proven to be easier to use than Gazebo [30].

Current robotics designs used by the students are not so complex. Therefore, as future work, we plan to add to the platform the robotics operating system ROS, which will allow developing better movement simulations thanks to the nodes, tools, libraries, messages definition, services definition, and configurations provided by this software. The implementation of such functionality will allow obtaining a better teleoperation when the simulated model is implemented in real-world scenarios. Finally, we plan to integrate to the platform 3D design functionalities, by means of which students can design and print components of the robotic prototypes.

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