Design of a remote 3D printing laboratory prototype to be implemented at the Universidad Cooperativa de Colombia

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Abstract. This paper presents the design of a remote access laboratory, which will allow students and professors to interact and perform through the Internet, modeling processes and CAD printing practices by means of a 3D printer. It is proposed to implement a hardware and software system that will allow to monitor and control variables remotely, from a computer, located in the automation laboratory of the Universidad Cooperativa de Colombia, Bogotá campus. The main problem that motivated the development of this research, arises from the current pandemic and the impact it generated for the Universidad Cooperativa de Colombia, forcing it to temporarily close its headquarters and reinvent its teaching models, although there are different technological platforms that successfully replace the classroom teaching model through virtuality, the institution still has a major drawback with the development of their practical classes. This research was carried out through the analysis of data that allowed to accurately identify the type of practices, the number of students per practice and the most used laboratory equipment, which was done in order to identify the different variables that led to determine the type of laboratory practice that would fit the design of the remote laboratory.

Introduction

The Automation Laboratory of the Universidad Cooperativa de Colombia has a 3D printing tool, which is used by different programs of the Engineering area, being a fundamental support in the elaboration of research projects and academic processes. Although the physical and technological infrastructure is adequate for the proper functioning of the printer, it requires the organization of appropriate schedules for the manipulation of the tool because there is only one printing equipment, limiting its use.

The design of the remote laboratory for the practice of the 3D printer arises from the need to implement new technologies combined and readapting the theoretical and practical classes to a remote environment with the help and effort of their students and teachers. The benefit lies in the possibility of connecting with the university and making use of its services in an efficient way due to the management of information and communications. This project will greatly optimize the management of information and provide greater control in the university [1].

It is important to highlight that the proposal to design a remote laboratory for a 3D printer is favorable for end users since the system does not only consist of a remote printing service, but the user can remotely and autonomously manage the 3D printing, allowing to schedule appointments in real time to avoid user crossings and manipulate the device from anywhere in the world, favoring the creation of future 3D printing projects [2].

The remote laboratory is intended to provide the academy with new spaces to develop their practices, connected from anywhere in the world, providing a number of advantages when implemented to a 3D printer [3]:

- The 3D printer can be located away from the operator's work area, which reduces the noise and odors generated by all 3D printers.
- Reducing wiring and centralizing it in a single unit offers easier maintenance and a more careful configuration.
- The 3D printer can be controlled and monitored with a mobile device, allowing virtually any user to make use of it.
- Sharing a 3D printer is easy. The process will be guided by a print web server.

- The 3D printer can be controlled from anywhere in the world on the Internet.
- 3D printing times are improved, since it is not conditioned to schedules, it is possible to print at any time and from any place.
- Ease of operation by any type of user, the user is able to print without the need to set new print configuration parameters.

Related studies

Within the research process, the exploration of background and existing documentation was carried out through databases for the collection of projects and related papers, which, in a sensible and focused way, are adjusted to the topic of remote laboratories [4]. According to the characteristics, objectivity and purpose of each of the related documents, they were grouped into different categories of analysis in order to synthesize them in an easy and organized way.

Most of the related papers are associated within the category of server implementation, since they expose the design and development of the interconnection software, the use of data and the access control system for the interaction between the student and the equipment, identifying the types of access that they handle for the execution of remote laboratory practices, with a methodology based on communication protocols [5] and platform connection [6] and [7]; in other papers such as [8], the implementation of servers is related to other categories of analysis such as virtual platform development and information security, where they show stable software and hardware architectures, client-server interconnection designs, network protocols such as TCP/IP and the implementation of a WebLab of programmable logic devices. In the same way, in papers such as [9] and [10] the category of data storage is intertwined with the implementation of servers for remote access with control of physical systems by means of virtual instruments oriented to learning and teaching in automatic, through the Internet.

Additionally, the development of virtual platform is another category of analysis where many of the related works are grouped, in which they describe the use of web applications focused on the design of the work interface and the times for the emulated system, both in real and virtual time, for the implementation of remote laboratory practices [11]; as well as [12] described two types of interfaces used through the java programming language (GUI and API), being the first one a graphical interface that allows the user a guided access to the objects contained in the laboratory and the API interface (Interface Application Programming), which allows developers to create local programs that will give them remote access to several laboratory resources at the same time, relating the development of the platform with the category of information security analysis.

On the other hand, in the paper [13], they developed Wategay4Labs, an interface that allowed them to integrate multiple remote laboratories in multiple learning tools, in order to convert a private remote laboratory to a public one where anyone in the environment can use it, allowing partnerships with different universities and thus generating a cost reduction and maximizing the use of laboratory equipment. The same as [14], which implemented an adaptive remote laboratory with the help of software integration, where the student has the ability to store the information of the experiment or practice to be performed, visualizing the procedure through remote laboratory interfaces. These last two related papers fall into the categories of information security analysis, data storage and development of virtual platforms.

Methodology

Some studies on the implementation of remote laboratories make known the importance they mean and the benefits they represent for the entire academic community [15]. For this reason, it begins with the development of documented research with the models and characteristics of the intermediary prototype that allowed establishing a remote connection with the automation laboratory, this type of remote communications required a structure comprising a physical infrastructure, conceptual development, an interactive virtual platform, management and security mechanisms, and evaluation methods [16].

This document was developed from a descriptive research. This method allowed the study of a set of practical and logical processes[17], which also allowed a more efficient approach to the design of the remote laboratory prototype. With a quantitative approach, the number of academic programs and number of students are analyzed and determined, determining the most appropriate laboratory practice for the design of the remote laboratory.

In this way, the construction of the design of a prototype of a remote 3D printing laboratory was carried out taking into account the analysis of information from the automation laboratory of the Universidad Cooperativa de Colombia, the design of the software so that users can perform the practices remotely; and the design of the hardware for the interconnection of the equipment, camera and different physical components of the laboratory, achieving the objectives proposed in the research.

3D Printer

This remote laboratory prototype is based on the use of the 3D printing device that is physically located in the automation laboratory of the Universidad Cooperativa de Colombia, Bogotá, where different laboratory practices of different academic programs are developed.

The melephant makeblock 3D printer shown in Figure 1, which has an open source, stable and concise structure with Prusa i3 aluminum frame and OLED display design with mobile base; from the electrical part it contains a RAMPS 1.4 and a Shield 2560 that work together and compatible, programmed by Cura software. This device performs high quality 3D printing and extreme precision, as it is configured with an XY resolution of 0.1 mm, layer resolution from 0.1 to 0.3 mm, allowing to create Art Craft prototypes, printing models, sculptures and even toys.

Figure 1. 3D printer.
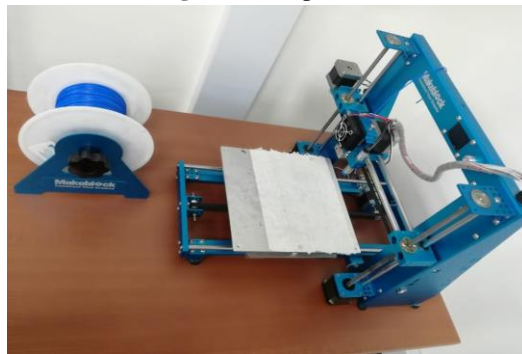
Source: the authors.

Remote 3D printing lab prototype

The structure of the prototype of the remote 3D printing laboratory that was designed is shown in Figure 2, consisting of a computer to which the user connects remotely through the application designed and from where the 3D printer is programmed with the Cura software, a push system that is activated autonomously to remove from the printer the objects that remain there once the printing is finished, two web cameras to view from different angles the object that is being printed, and a tray to store all the objects that are printed at the time.

**Figure 2.** General structure of the remote laboratory prototype.
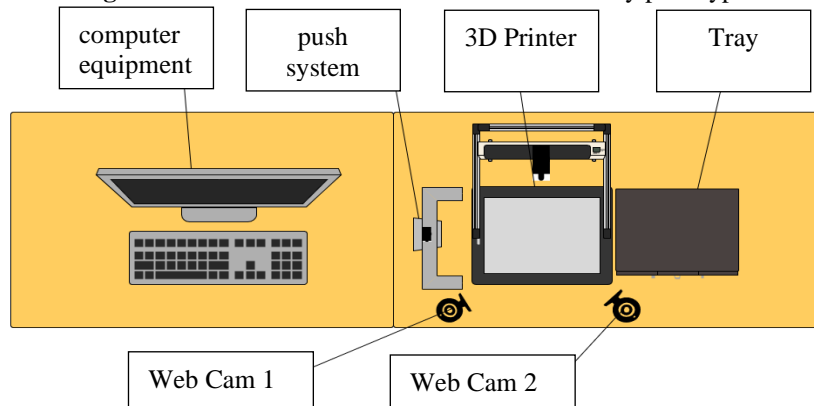
Source: the authors.

Database programming

For the development of the software to be implemented in the automation laboratory, the work started with the creation of the database to store the information of students and teachers who will enter to perform some laboratory practice as shown in Figure 3. In the XAMPP CONTROL PANEL software [18] the MySQL and Apache modules are enabled to have communication to the database and thus access the configuration and creation of tables.

Figure 3. Design of the login database.
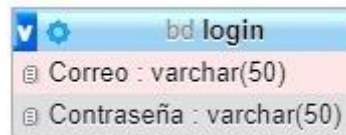
Source: the authors.

Once these services are configured, the port through which it is enabled is observed, in order to access the Localhost of PhpMyAdmin [19], where the database was created in which the personal information of all users is stored at the time of registering to book the laboratory practices as shown in Figure 4.

Figure 4. Design of the registration database.

Source: the authors.

Programming the interconnection interface

The interface and connection was built by the NETBEANS software [20], in which a large part of the program is implemented, since it is where the interconnection of the devices and the connection to the database was programmed as shown in Figure 5, where the library was added with its MySQL connector to have communication with the database created, additionally it is passed to the construction of the interface of the registration system; The JPanelWebCam library was also added for the interconnection of the webcams and the JDK complement for the application to be executed every time the user wants to enter the remote laboratory [21].

**Figure 5.** Interconnection interface configuration.
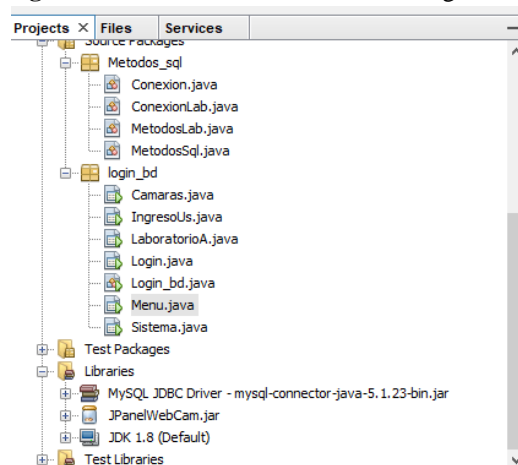
Source: the authors.

Connection of devices

The general connection scheme of the different devices of the remote 3D printing lab prototype is shown in Figure 8, which are connected as follows: the two webcams are connected via USB cable, the 3D printer is connected via USB Type A cable, as well as the pusher system is connected via USB Type A cable.

All three devices (3D printer, pusher system and the two webcams) are connected to the same computer, since from this computer the teachers and students connect remotely to perform the practice on the 3D printer, and at the same time they can observe from the two webcams what is being printed. Finally, this computer is connected to the internet through an ethernet cable that is routed from the server by the university's service provider.

6. General connection diagram.
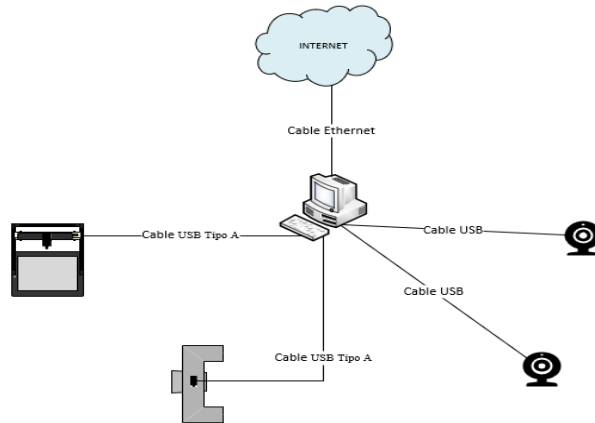
Source: the authors.

Results

As a result of the design of a 3D printing remote laboratory prototype, initially the study and collection of information is shown, in order to establish the type of laboratory practices that were implemented in the remote laboratory prototype, related in Table 1, starting from the number of courses and academic programs that perform laboratory practices, the number of students, the number of practices and the amount of equipment used in the practices of the automation laboratory of the Universidad Cooperativa de Colombia.

Table 1. Automation laboratory data.

Course Name	Academic Program	Total Students	Total Internships	Laboratory Equipment
Robotics Seminar	Electronic Engineering	9	28	Robotic Arm
Electrohydraulics - Pneumatics	Electronic Engineering	6	24	Electro-pneumatic module
				Pneumatic bench
Methods and Time Engineering	Industrial Engineering	15	12	Quality control bench
				Cutting bench
				Conveyor belt
Industrial Electronics	Electronic Engineering	8	22	Job title
				PLC
				Electro-pneumatic module
Control III	Electronic Engineering	22	30	Job title
				Quanser Module
Control II	Electronic Engineering	9	23	Job title
				Quanser Module
CAD systems	Industrial Engineering	16	10	3D Printer

Source: the authors.

It can be identified that the 3D printer, used in the CAD systems course of the industrial engineering program, is the laboratory equipment with the lowest tendency in the efficient use of laboratory practices, as shown in Figure 7, because it requires the teacher or the student to be present at the university facilities to carry out the laboratory practice.

Figure 7. Diagram of the number of practices performed in each course.
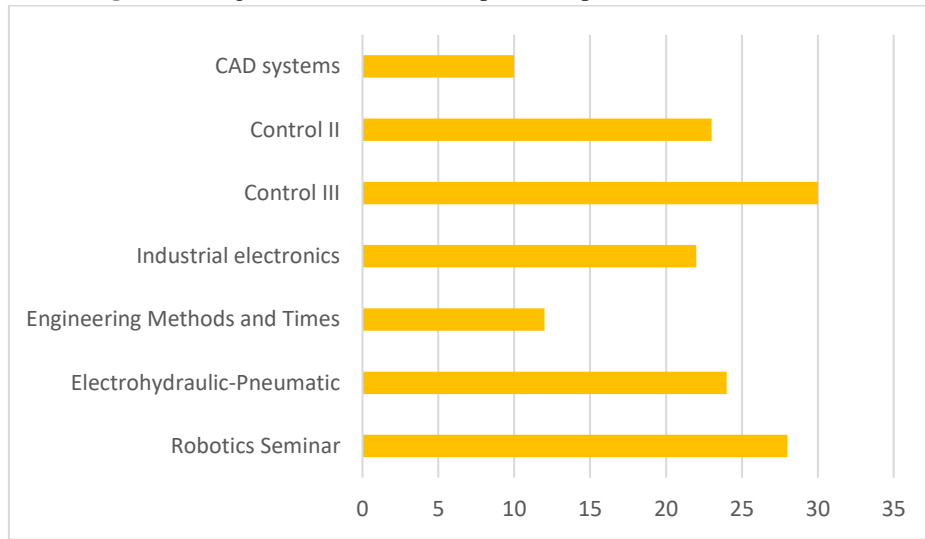
Source: the authors.

In the same way, as a result of the project, the operation of the application for the interconnection and use of the remote laboratory prototype is demonstrated, explained step by step for the registration, use and reservation of the laboratory practice.

1.   Access menu:

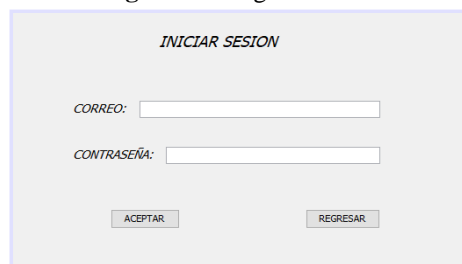**Figure 8.** Access menu.

Source: the authors.

Two accesses are provided in the access menu as shown in Figure 8, being this the main menu to which the teacher or student will initially access. Figure 9 shows the first access for user registration, in the case of not having a username and password to enter, this option requests a series of personal data that will be stored in the database created once the information is provided; the second access leads to the login as shown in Figure 10, once registered, the system will request the email and password that was registered to access the remote laboratory.

Figure 9. Registration window.

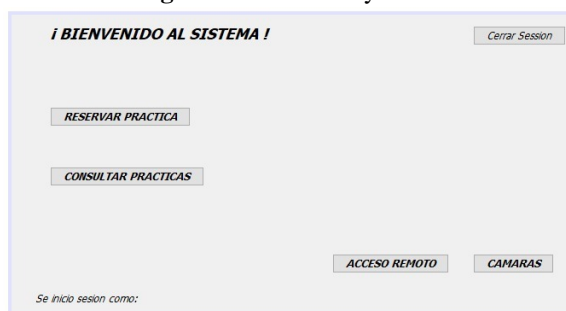Source: the authors.

Figure 10. Login window.

Source: the authors.

2. Laboratory menu:

After completing the registration and access process, the user will find in the following interface the menu shown in Figure 11, where he/she will be able to consult the reserved practices, where he/she will find the name of the user who has already reserved, the time and date on which the practice is scheduled; also, in this mode the student or teacher can reserve the practices that are necessary, taking into account the reservations made by other users so as not to have any cross over with another practice; finally, he/she can start the scheduled practice.
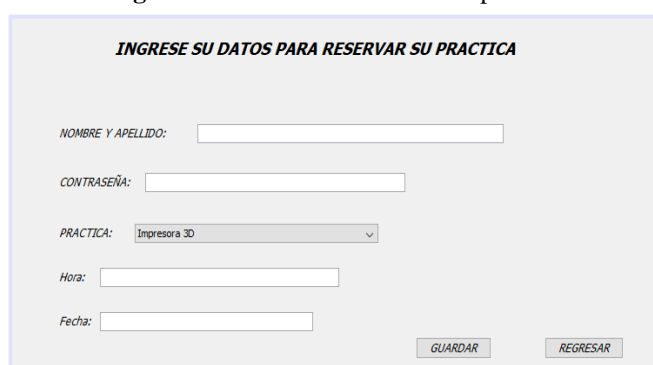
Figure 11. Laboratory menu.

Source: the authors.

At the moment of entering to reserve the practices to be developed, the system requests a series of personal data as shown in Figure 12, such as: the name of the student or teacher, time and date to carry out the practice and the type of practice to be implemented together with the password with which he/she enters the system.

**Figure 12.** Window to reserve the practice.

Source: the authors.

Once the reservation is made and the practice begins, the application will allow the teacher or student to access the remote laboratory where access to the webcams can be found as shown in Figure 13 and Figure 14. In the other option of the laboratory menu, the remote access can be accessed to interconnect with the laboratory computer, where the printer can be programmed with the Cura program and thus finally be able to perform the practice from the remote laboratory prototype, as shown in Figure 15.
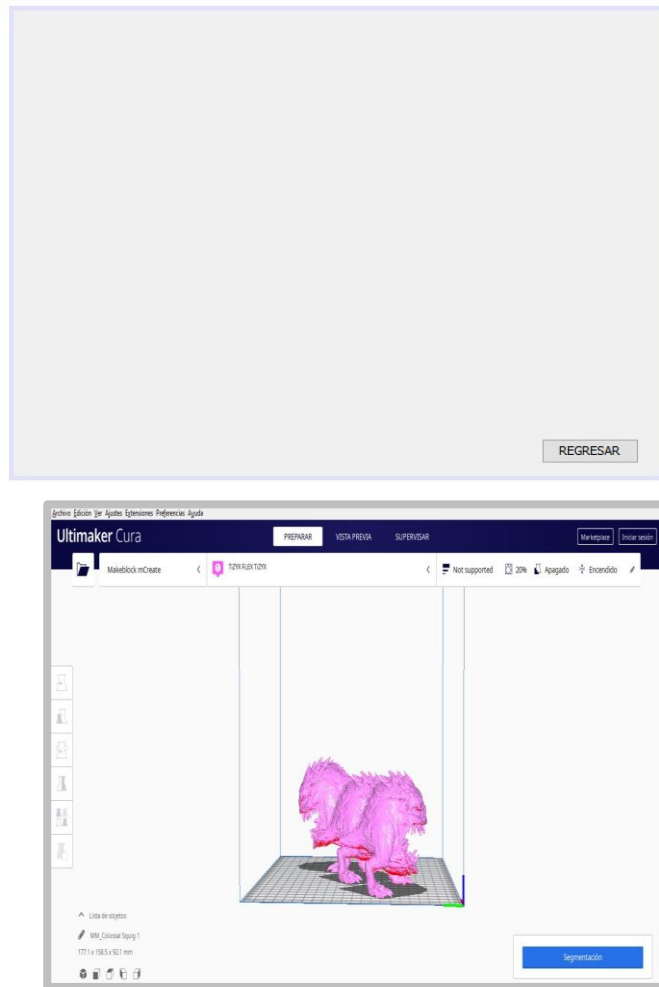
Figure 13. Webcam window 1.
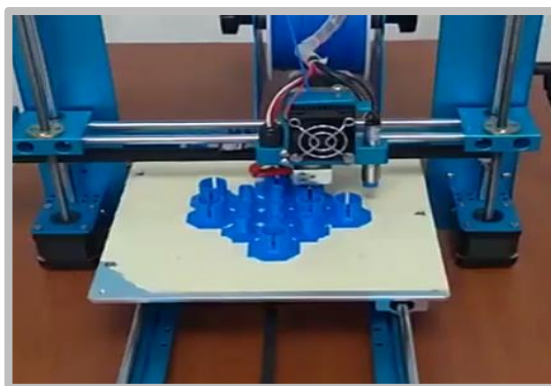
Source: the authors.

Figure 14. Webcam window 2.
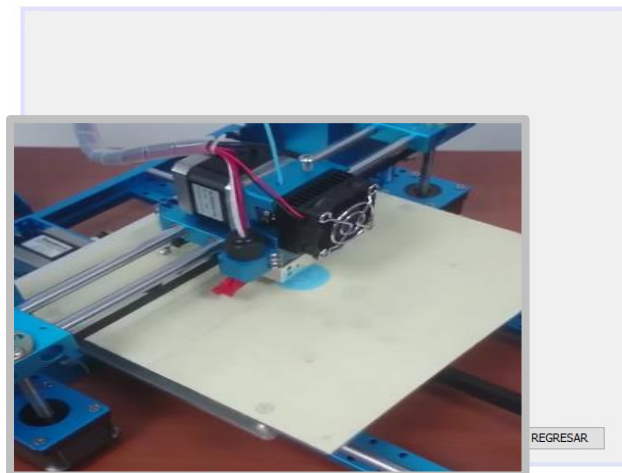
Source: the authors.

Figure 15. Remote access window.

Source: the authors.

Conclusions

Remote laboratories generate a more comprehensive theoretical and practical learning, incorporating new teaching strategies so that the user can interact in a real way with the laboratory equipment without having to be in person at the university facilities, eliminating travel time and encouraging the good use of students' free time.

The design of this remote 3D printing laboratory prototype will allow researchers, professors and students of the 12 campuses of the Universidad Cooperativa de Colombia nationwide, where the faculty of engineering is present, to make use of this device from their homes or from any branch, headquarters or extension center of the university; generating a greater reach for the entire educational community, taking into account that currently the 3D printer is located at the Bogotá campus for the use of its professors and students.

The use of the remote laboratory, focused in this case to the management of the 3D printer, offers the students of the Universidad Cooperativa de Colombia to develop and achieve with greater care the competencies of the CAD systems course or any other, strengthening the academic and research training for the execution of projects and innovation.

The costs of adapting on-site laboratories can be excessive when compared to the implementation of remote laboratories, which allows the integration of several practical learning environments through software development platforms, facilitating the use of laboratory equipment and optimizing physical infrastructure costs.

In other words, remote laboratories are the best learning tool that any educational institution in the world can have.

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