# Virtual Training for Industrial Automation Processes Through Pneumatic Controls

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**Abstract.** This work presents the implementation of virtual environments oriented to managing pneumatic controls applied to industrial processes in order to strengthen training and teaching-learning processes. The implemented application enables the multi-user immersion and interaction with the aim to accomplish predefined tasks to be developed within lab environments and virtualized sceneries for industrial processes. Obtained results show how easy it is to interact with the proposed multi-user environment.

**Keywords:** Virtual Reality · Training · Capacitation · Industrial processes Multi-user

## 1 Introduction

The technological age of society has made changes in several areas such as industry, health, training, education. A world which has been inserted in daily life has been generated, transforming habits, customs, and personal preferences [1, 2]. Education is not far from these constant changes which have created a notorious difference between traditional education and modern education. The traditional approach was focused on transmitting knowledge unilaterally through a teaching process subject to didactic and pedagogical methodology limitations [3]. This approach is replaced by modern education which allows transmitting knowledge bilaterally through a teaching-learning process. In this approach, the teacher-student interaction is performed in an active way through modern pedagogical tools [4, 5].

The implementation of Information and Communication Technologies, ICTs, complement and transform education through a group of techniques, tools, and advanced devices, which allow the student to access, generate, and transmit information and knowledge [6]. The implementation of ICTs has developed applications such as interactive rooms, virtual labs, simulators, and more. These apps let innovation

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processes to be oriented toward several environments in order to promote building more dynamic and interactive learning spaces [7–9]. In recent years, education has implemented Virtual Reality, VR, and Augmented Reality, AR, applications, with the aim of introducing students to immersive and multi-sensorial environments, in which students interact within a virtual environment that stimulates the teaching-learning process, allowing the teacher to complement knowledge given [10–12].

VR allows learning in different knowledge areas to be complemented, such as medicine, marketing, and engineering, thus enabling the future professional to interact with real environments through simulators [13, 14]. On the engineering field, applications which are focused in automatization, control and instrumentation, are presented. Here, theoretical knowledge is complemented with practice through the manipulation and control of equipment and electronic devices [12–14]. The development of emulators for industrial processes allows the student to complete training by interacting with equipment and processes in the industry, allow the student to know, analyze, and implement real processes within virtual environments. Therefore, the interaction and immersion in 3D animation, standardized regulations management, and communication with industrial teams, is important [15–17].

Engineering majors must be closely related to the latest technological tendencies applied to the industry. However, the existing budget limitations in the universities stop the implementation of laboratories for each area of studies. That is why, taking advantage of Virtual Reality sources on this work, the implementation of a VR environments with pneumatic controls is proposed. This application has two parts*: (i) Virtual Lab* oriented to developing practices in subjects for industrial control, pneumatic and hydraulic matters, where it is possible to manipulate each lab component and carry out lab classes guided by the teacher, who can also work with multi-user feature as an advantage. Then, it is possible to interact with all lab users as an essential part in the teaching-learning process, and *(ii) Industrial environment*, where VR industrial environments are developed; this make it easy to include the student into a virtual environment where it is possible to identify the process, thus, the student has a work experience in an industrial facility, following regulations and safety procedures, and has the possibility to manipulate and operate machinery during the process. In addition, the student can all acquired knowledge for solving a real problem that may occur in the industrial plant.

This article is divided into 5 Sections including the Introduction. Section 2 describes the system description of the working environment; Sect. 3 describes the multi-layer scheme of the virtual environment development application. Section 4 shows the methodology and discussion that validate the proposal; and finally, the conclusions are detailed in Sect. 5.

## 2 System Description

Figure 1 illustrates the description of the developed VR application. It represents the interaction of four main blocks: Scene, Inputs, Scripts, and Outputs. Their interaction generate a didactic learning environment and practices on the pneumatic controls field.

In the *Scene Block* is the Home, Laboratory and Tannery environment *(i) Home* contains the selection of scenes and certain additional configurations available to the

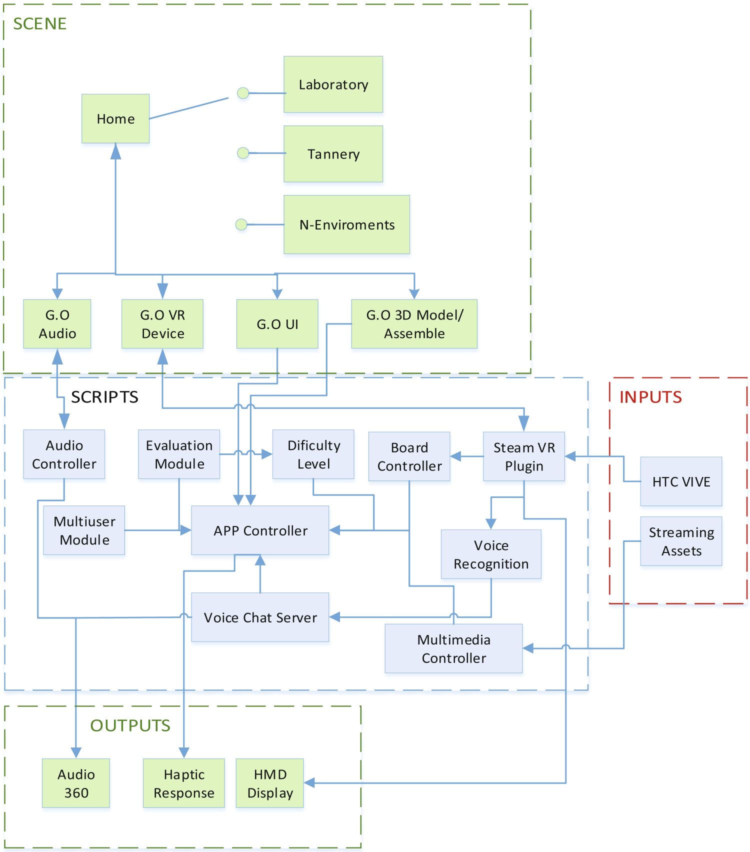



**Fig. 1.** System description diagram

user; *(ii) Laboratory*, preestablished practices with pneumatic controls are established, while in; *(iii) Tannery*, specific tasks related to maintenance, repairing and/or installation of pneumatic control systems are conducted, an analog practice compared to Laboratory. The system is scalable since it allows to add different scenes according to required needs. The elements which participate in each scene can be generalized through Audio Game Objects, VR Device, UI, and 3D Model/Assemble. All these respond to specific control modules, depending on the work objective that each scene has.

In the *Scripts block*, a group of interconnected control modules can be found. These modules enable to define the behavior of each developed environment. The SteamVR Plugin and Multimedia Controller manage the HTC VIVE and Streaming Assets inputs respectively. Meanwhile, the SteamVR Plugin gathers data from the sensors of HTC VIVE Glasses in order to be used by the APP Controller as an input method, and at the same time, reflected in the G.O VR Device. In order to detect the user's voice commands, a connection with the Voice Recognition module is established, which connects to the Voice Chat Server for transmitting audio to every user within the environment. Using this module requires a simultaneous multi-user connection when sending and receiving environment data. The connection is provided by the Multiuser Module.

Several modules have been developed for scenes to work, such as (i) the Evaluation Module in charge of establishing the user's score after performing a task in the selected environment, and (ii) Difficulty Level which contains the programing for the two difficulty levels in the system. The Board Controller has an additional functionality through the HTC VIVE Controller which is allowing the user to write on a virtual board and project audio visual content through the Multimedia Controller module. The Audio Controller module manages audio sources generated between the object interaction and user's communication. Data is sent to G.O Audio, and as Audio 360 when it is released.

The ideal HTC VIVE Glasses for the current application can be found in the *Inputs Block* since their work space requires 12 $m^2$ and has a tracking system for the HTC VIVE Controllers. The Streaming Assets are also present as external audiovisual resources regarding the application. They are available locally or in the network.

In the *Output Blocks*, a relation among components takes place, such as Audio 360, Haptic Response, HMD Display, which come from HTC VIVE glasses, the hardware used. The Audio 360 module reproduces environment sounds, Haptic Response provides a haptic feedback when interacting with an object, and HMD Display represents images captured by the camera according to the user's interaction within the environment.

## 3 System Development

To conduct an industrial practice or experience within a virtual environment, the physical-technical features must be as real as possible, for instance, size, shape, and functionality of the elements which interact under a specific practice. This way, the user can be provided with the required immersion for the development of a specific task. With this premise, Fig. 2 shows the elaboration and implementation sequence for a virtual lab. This sequence is divided in four stages.

In the *first layer*, modeling elements and objects is considered, which is developed through: (i) 3D design; it is necessary to design in 3D each system element and object according to the lab to be implemented (valves, resistors, capacitor, pistons, engines, pumps, among others). For the modeling, a design software supported by the computer (CAD) is used; the modeling makes it possible to analyze the physical characteristics (size, shape, texture, among others) of each element and device. There are tools such as SolidWorks, Autodesk Inventor, AutoCAD, among others, which allow the user to design the necessary elements to conduct a practice, and (ii) Mechanical Interrelations; this stage considers position and movement transmission interrelations of each object in the virtual environment. The coordinated interaction between two or more objects participating in a specific task will depend on these interrelations.

On the *second layer*, work is done on 3D models developed in the previous stage. The following aspects are considered in this stage*: (i)* 3D features edition; in this stage, the system axis to work with are established as a reference to new objects. Modeling software is used in this phase such as 3DSMAX or Blender. Device parts are distinguished; each element is treated differently since pieces are static elements which provide no response but are present during the practice, and devices which are dynamic

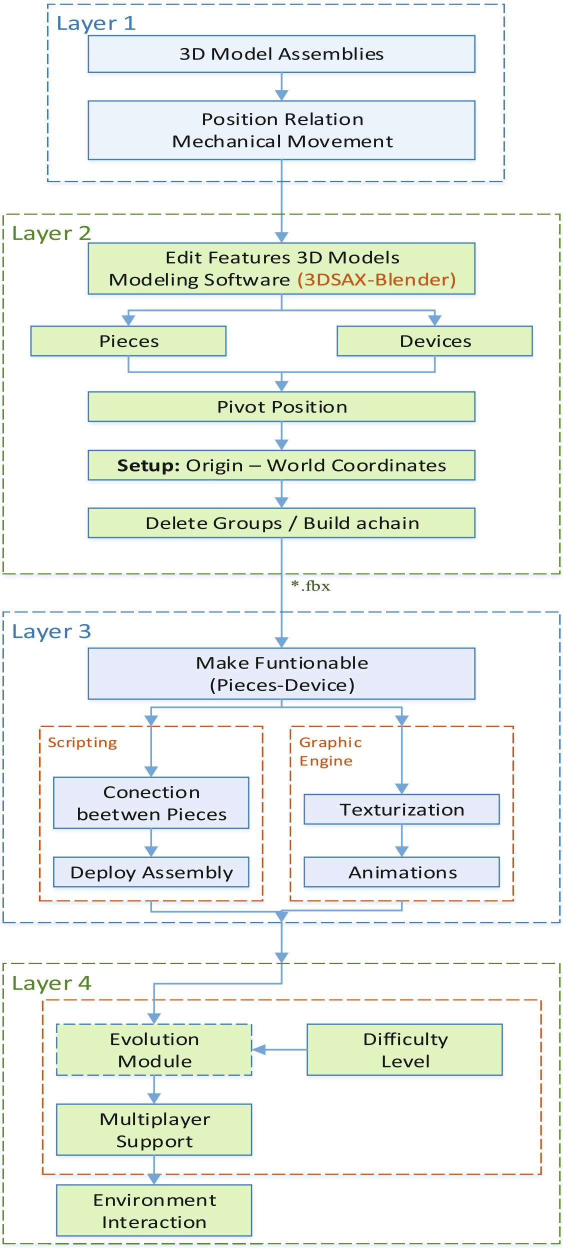



**Fig. 2.** Component interrelation diagram

elements that respond to input stimuli and provide visual or auditive output response; *(ii)* Pivot set-up; the individual pivot point for each piece and device is set. This point is generally located outside the object. Therefore, it is convenient to place this point in each object's geometrical center, so they can rotate or turn around their own axis; *(iii)* Origin placement; the global reference system is determined in this stage. In addition, a reference to the local coordinates system of each object in respect to the global coordinates system is made, as part of the good practices in editing 3D models. Finally, this layer considers; *(iv)* Groups deletion; there are three ways to group objects to be exported: blocks, groups and chains (hierarchies). By default, files are exported in blocks. To develop this application, files are exported in chains since hierarchies, and movement transmission of pieces and devices are kept. These files are exported with the *.fbx. extension.

For models to be functional, Scripting and Graphic Engine tools are used. Thereby, the *third layer* has been subdivided into two subsections (a) Scripting, where the following are developed: (a.1) Connection scripts; a code is implemented for objects to be able to connect and interact with each other, and physical principles which rule the response of each object are implemented; (a.2) Deploy Assembly, this process allows observing the behavior and responses of objects connected to each other. The second subsection considers layer (b) Graphics Engine in which the following stages are considered: (b.1) Texturization where color and realism is given to elements and objects so they behave as real ones; and finally (b.2) Animation in which dynamic elements get animated so as to display certain variation on the interaction among objects.

The *fourth layer* consists of assessment stages and multi-user interaction, where the following is considered: (i) Assessment module where the functioning assessment algorithm for a specific process or practice is implemented, considering different difficulty levels in order for every process or practice to be enrich the teaching-learning process with experiences; and (ii) Multiplayer support which implements the module for each user to make use of the previously developed blocks. This module allows users to interact with each other within the same environment.

## 4 Methodology and Discussion

This section describes the performance of the 3D virtual application developed, which considers two environments that allow the interaction and immersion of the user in order to strengthen the teaching-learning process in the area of engineering, specifically in pneumatic controls. The developed environments can be selected by the user according to the level of learning, see Fig. 3.

Figure 4 shows the requirement for the input of student personal information in order to keep a record of access to the virtual environment and to identify the type and manner of compliance with the activities planned by the teacher in the implemented work environments.

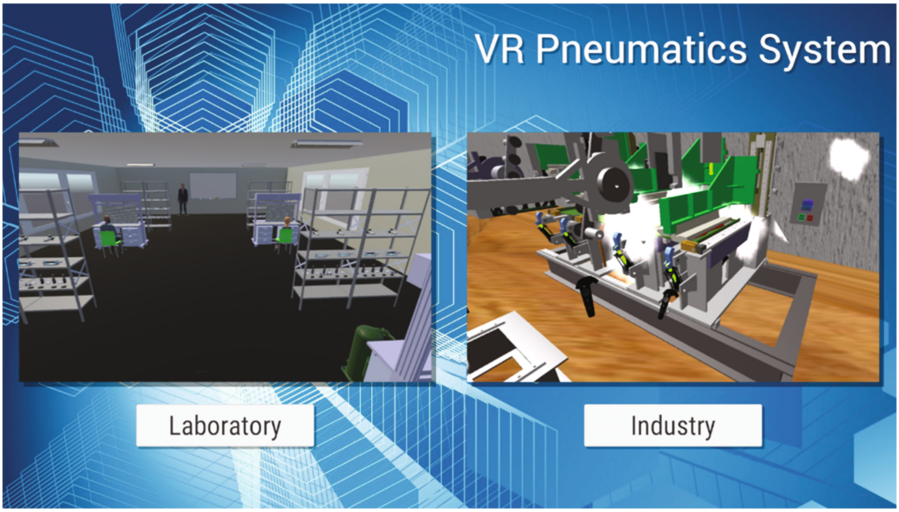



**Fig. 3.** Working environment selection

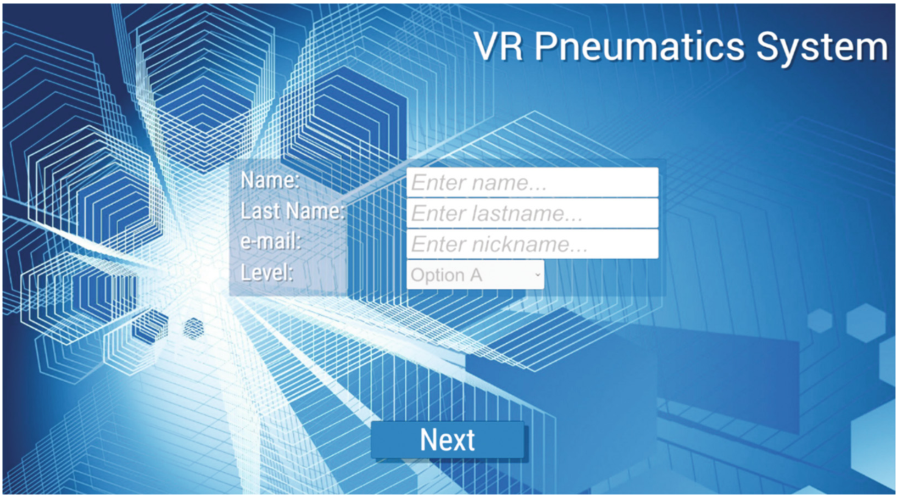



**Fig. 4.** Entering personal information

A. ***Virtual Laboratory*** oriented to the development of guided laboratory classes in order to recognize, manipulate and control the different equipment-materials related to the area of pneumatic controls. Figure 5 shows the scenario developed.

The stage is equipped with materials found in real laboratories, with a wide variety of single-acting actuators, double-acting actuators, regulating filters, pressure gauges, limit switches, exhaust valves, pushbutton valves, simultaneity valves, compressors,

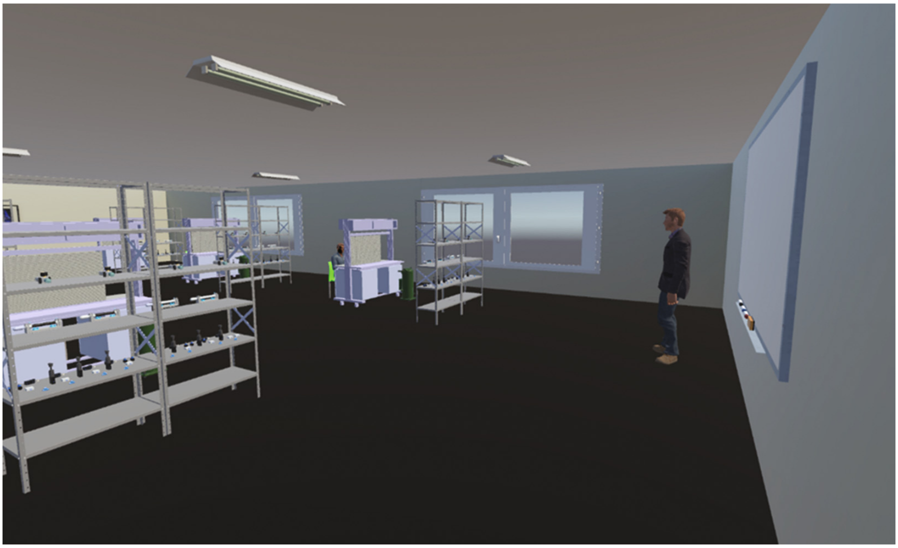


**Fig. 5.** Virtual laboratory scenario

festo work tables, as illustrated in Fig. 6, so that students can assemble different pneumatic circuits without any limitation of equipment or materials.

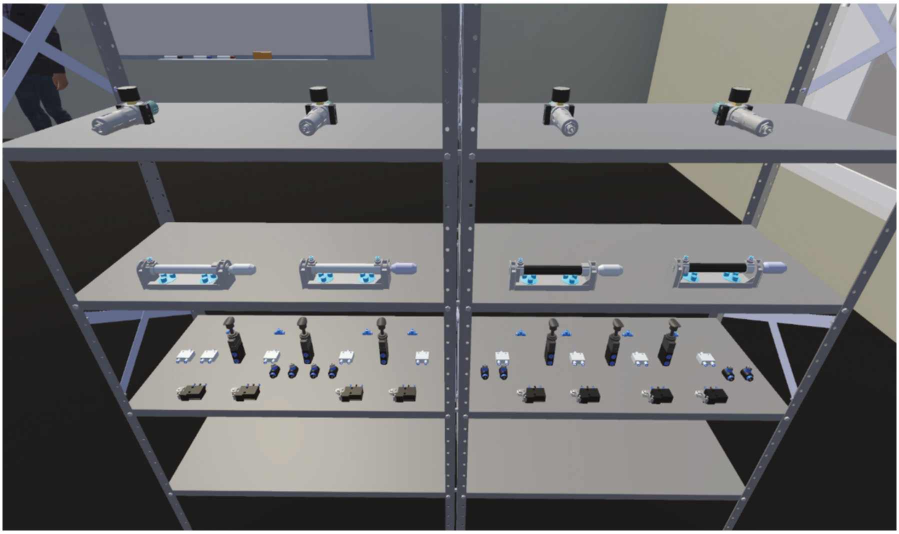


**Fig. 6.** Virtual laboratory materials

Figure 7 illustrates the multi-user interaction, which aims to enable several users (teachers and students) to interact in the same environment.

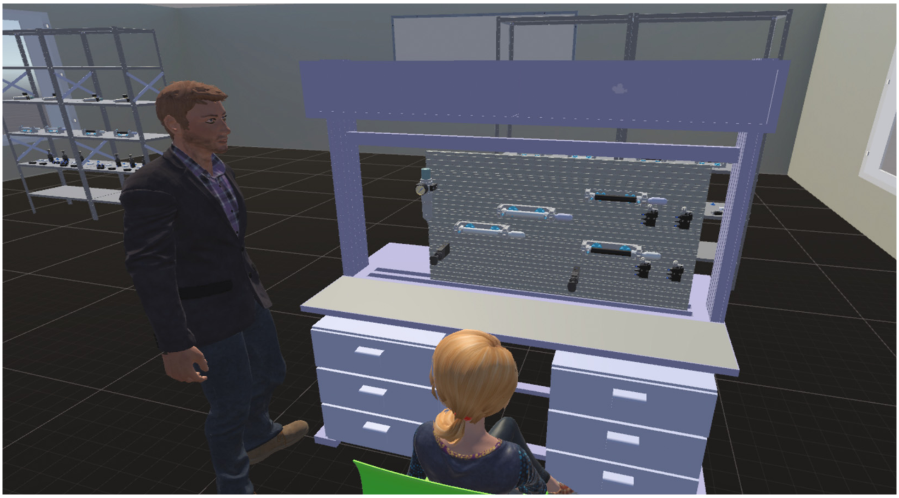


**Fig. 7.** Multi-user interaction

The task is selected and displayed by the teacher to the students through a virtual pneumatic diagram as illustrated in Fig. 8, which shows the necessary analog virtual machines and construction instructions, allowing the student to follow a series of steps to complete the task correctly. The diagram shows a drive sequence A+B+A–B–.

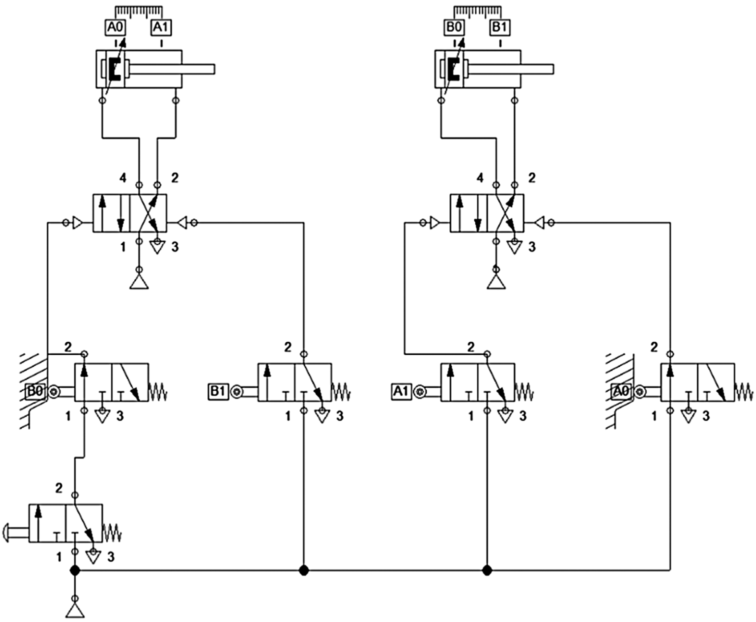



**Fig. 8.** Virtual pneumatic diagram

The level of difficulty of the system will increase according to the teacher's instructions or due to the student's performance in the construction of pneumatic diagrams, in initial levels the system will indicate the type and location of the elements as shown in Fig. 9; and as the level of difficulty increases the indications of help will decrease until it disappears allowing the student to construct the pneumatic diagrams completely alone.

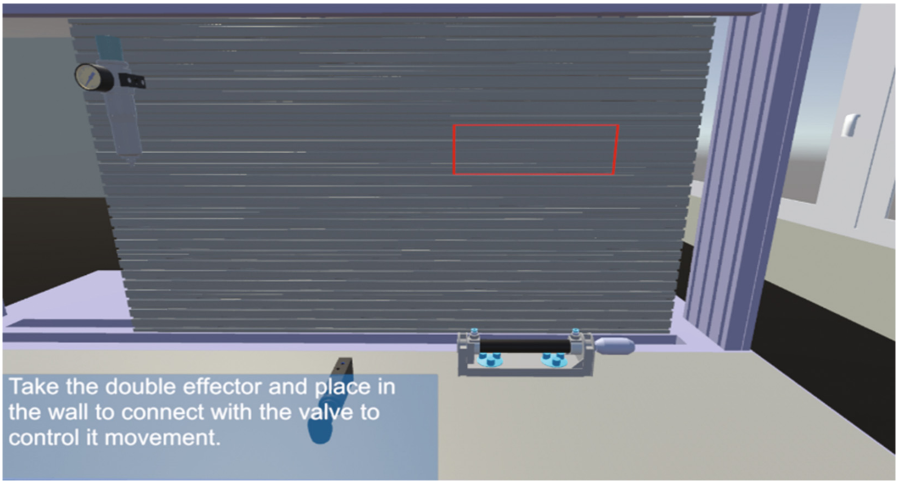
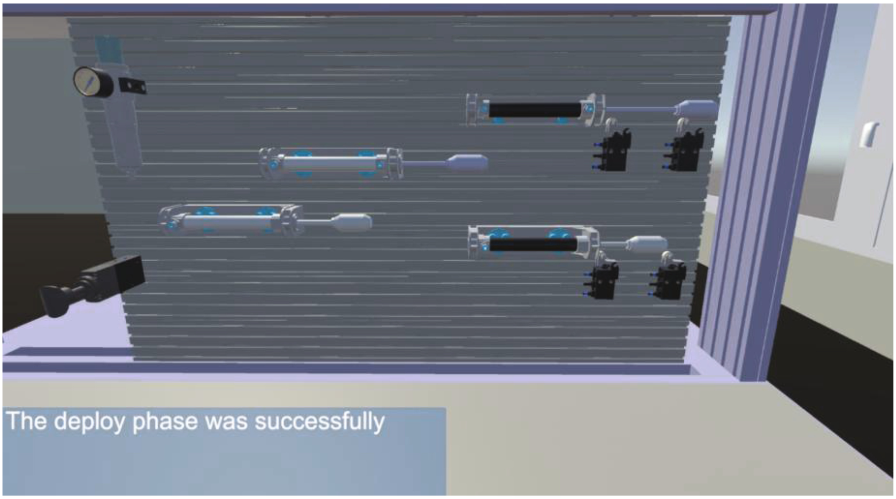



**Fig. 9.** Visual and textual help at difficulty levels

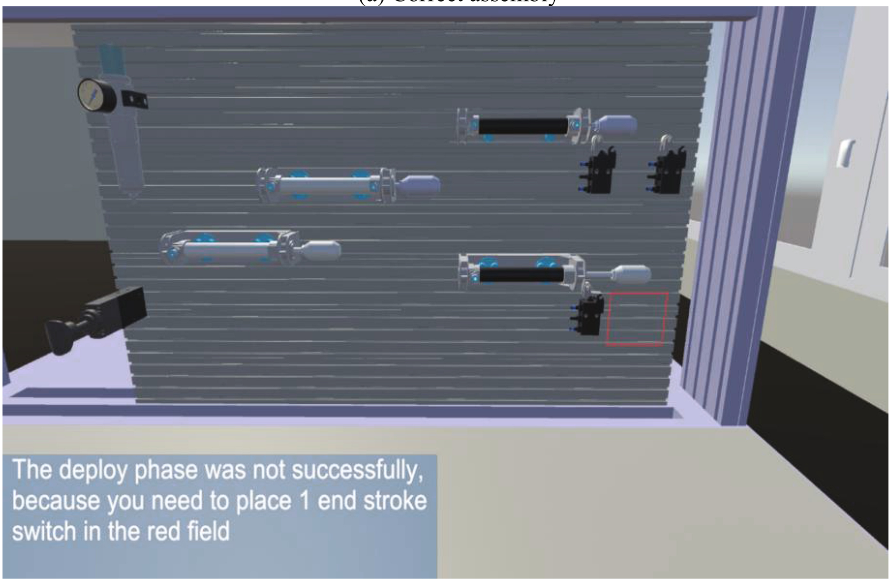
Once the construction of the pneumatic circuit is finished, the process of DEPLOY is started, which allows to check the correct functioning of the circuit, i.e., if the circuit assembly is in good working order, the animation of valves, pistons and other elements simulating the air flow will be observed as shown in Fig. 10a; if the circuit assembly is incorrect an error message will be displayed, illustrated in Fig. 10b.

The system allows the teacher to supervise the work done by each student from their respective module using locomotion techniques such as tele-transportation (see Fig. 11a), and also allows bilateral communication with the student via voice chat as illustrated in Fig. 11b.

The Audio 360 system implemented allows listening to sound effects such as reverberation, echo, distortion, among others, which is generated when the audio source is far from the audio Listener, which makes the experience is immersive and intuitive for the exchange of information by voice. In addition, the system includes a virtual whiteboard, where the teacher through a virtual marker can make pneumatic diagrams, explain different methodologies or techniques, allowing the teacher to interact with the student without restrictions of the system, e.g., generate a pneumatic




(a) Correct assembly




(b) Incorrect assembly

**Fig. 10.** Checking with DEPLOY (Color figure online)

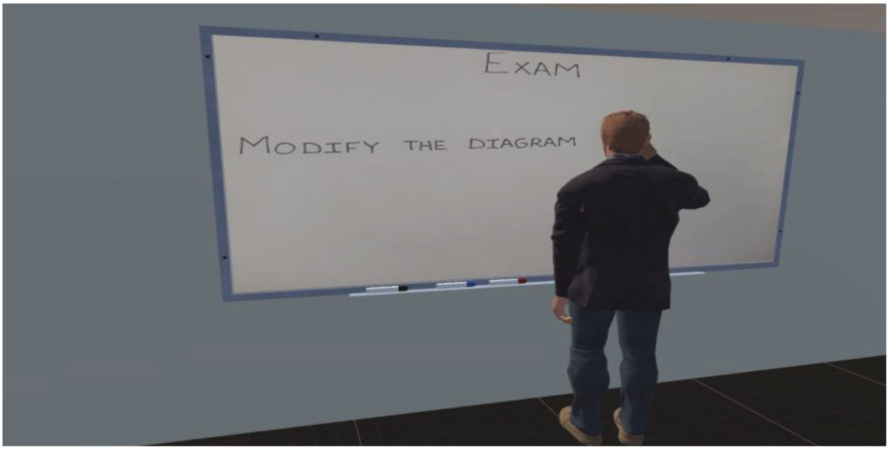
diagram in order to evaluate the student as shown in Fig. 12a. The same whiteboard is used as a projection screen for multimedia resources hosted on the web or locally. In the first interaction, a YouTube video is presented, showing the safety instructions for the entry and use of the laboratory (see Fig. 12b).

(a) Locomotion technique

(b) Chat of voice

**Fig. 11.** Teacher supervision

B. ***Industrial Environment,*** an industrial environment was developed oriented to the tanning of animal skins for the manufacture of clothing. The main objective of the application is to familiarize the student with real industry environments, making it easier for the student to immerse and interact in work environments where it is possible to identify the process to be controlled, in this way the student acquires a work experience, following safety rules and procedures, see Fig. 13.




(a) Teacher Interaction

(b) Projection of multimedia resources

**Fig. 12.** Virtual whiteboard

The virtual industrial process illustrated in Fig. 14, allows the student to become familiar with the handling and operation of tanning process machinery, applying knowledge acquired in the area of pneumatic controls to the solution of real problems that may arise in the industrial plant. The task performed in the industrial environment

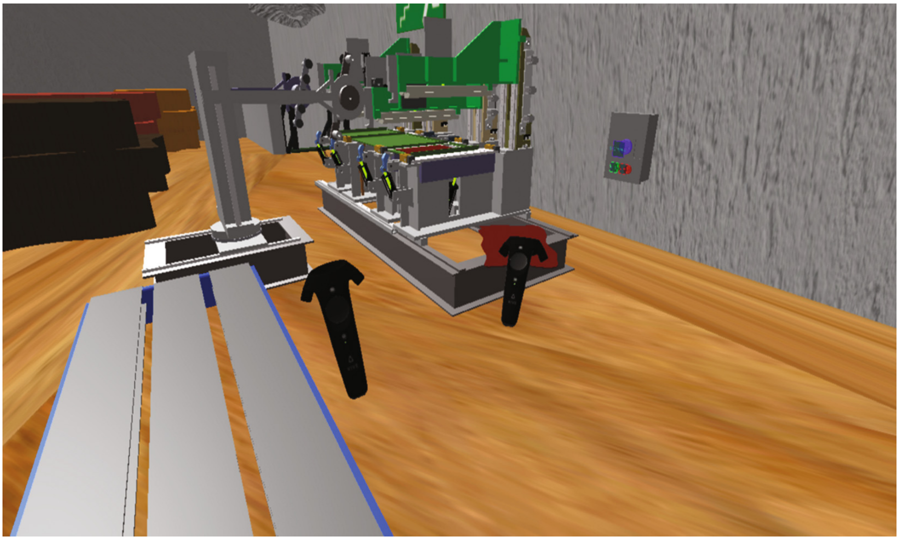


**Fig. 13.** Tanning process of animal skins

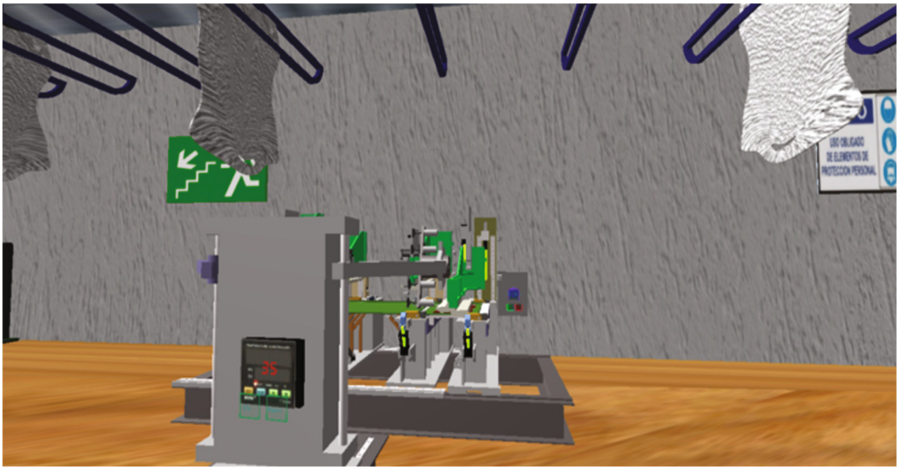


**Fig. 14.** Task in industrial environment

is like to that performed in the laboratory, but industrial elements are used and implemented in complex systems. Inside the industrial plant, multiple machines are used to finish the leather, one of them is the pneumatic ironing machine that removes wrinkles or imperfections from the leather, its function is based on pneumatic pistons which execute a control sequence based on the temperature, this is opened or closed flattening the leather and heating to the desired temperature.

To complete the task, proceed as follows: (*a*) *Step 1*, the user must place the safety elements and equip himself with the work tools (see Fig. 15a); *(b) Step 2*, locate the work area in order to suspend the process where the intervention will be performed (see Fig. 15b); *(c) Step 3*, proceed to assemble the parts according to the diagram with the specific tools (see Fig. 15b). Figure 15c; *(d) Step 4*, review the implementation and check that there are no missing or excess elements see Fig. 15d; *(e) Step 5,* activate the machinery and verify the correct operation of the implementation and the synchronization with the system Fig. 15e; *(f) Step 6*, clean the work area and consider the finished task see Fig. 15f.

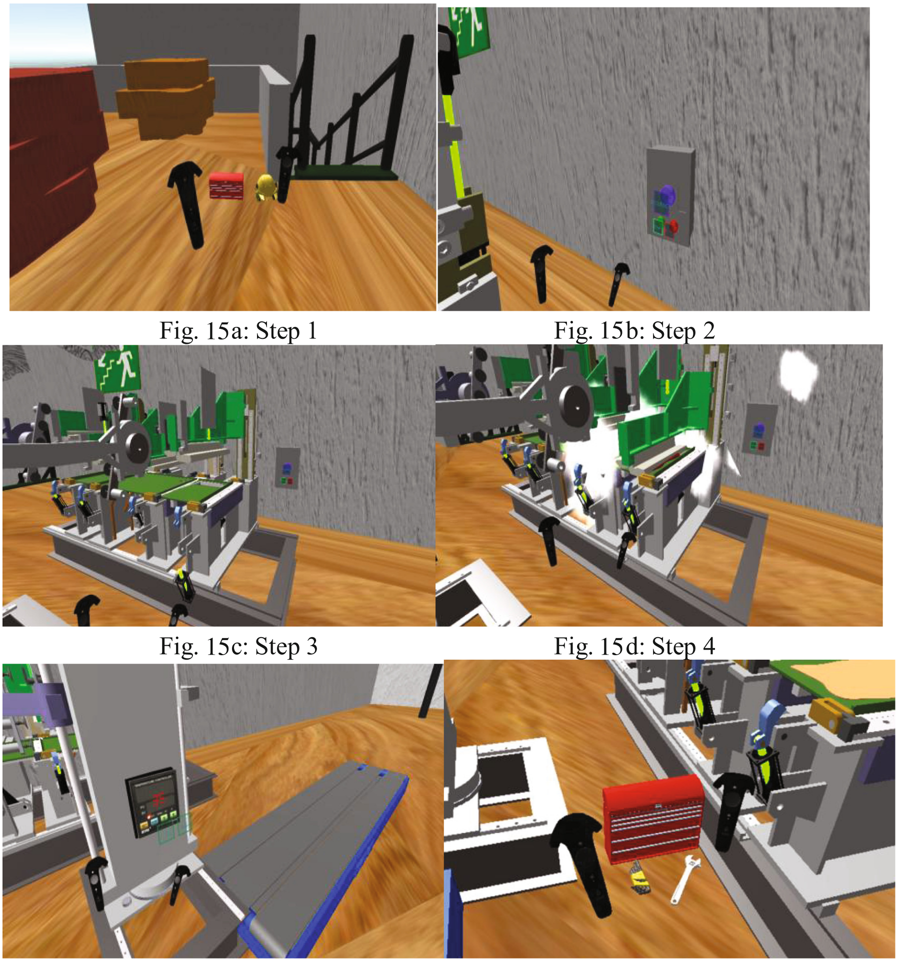


Fig. 15a: Step 1
Fig. 15b: Step 2
Fig. 15c: Step 3
Fig. 15d: Step 4
Fig. 15e: Step 5
Fig. 15 f: Step 6

**Fig. 15.** Process step

## 5 Conclusions

This work developed a Virtual Reality application in order to improve training and teaching-learning processes on the industrial procedures management field, specifically pneumatic controllers. The virtual app considers: *(i) Virtual Lab*, in which users take guided lab classes in order to manipulate and control simple pneumatic controllers' procedures, while in *(ii) Industrial Environment* allows users to become familiar with real environments in which they must develop their skills and abilities within real environments.

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