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Electropneumatic system for industrial automation: a remote experiment within a web-based learning environment

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Abstract

The design and implementation of a web-based laboratory, which enables engineering students to remotely perform experiments for an undergraduate course on industrial automation, is presented here. The laboratory was developed using LabVIEW® virtual instrumentation and it allows remote control and monitoring, in real-time, of the actual laboratory equipment. The experiment represents the automation of an industrial process by means of pneumatic equipment, which can be remotely operated from a web-based learning environment. The overall structure of the system and the developed virtual environment are described in this paper. The proposed system allows students to carry out experiments at their own pace and with less schedule and location restrictions than in conventional laboratories. The performance of the system was validated and evaluated by a sample of students in order to determine its functionality. Preliminary results obtained from the experimental set-up are presented.

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Keywords: web-based laboratory; remote experiment; e-learning environment; remote laboratory; virtual instrumentation.

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1. Introduction

In higher education institutions, experimental training is of great importance for a better understanding of the theoretical knowledge taught in lectures. Both fundamental theories and its practical application are essential in the learning process of undergraduate and graduate students. In science, technology and engineering fields, experimentation is particularly important since future engineers develop new abilities and they gain practical experience by means of handling tools and actual equipment which they will be interacting with in their professional environment.

Laboratories are the most important resources by which engineering students have access to practical experimentation and thus, an important issue for universities is to provide properly equipped laboratories. However, initial equipment of laboratories and its subsequent maintenance and periodic renewal require a huge and constant investment that a reduced number of public institutions are able to afford.

Besides the lack of economic resources, the limited flexibility of schedules and time to access the laboratories (imposed in most cases by working hours of staff), and the big amount of students wanting to carry out the experiments, make any available resources insufficient to provide quality practical training to all students. To cope with these problems, new technologies such as virtual instrumentation and the Internet are being introduced in order to implement collaborative schemes which allow sharing the available resources among different campuses and institutions. This trend is helping to reduce costs of equipment and to provide greater flexibility on schedules, thus giving the opportunity to a larger amount of students to perform experiments at their own pace, from anywhere and at any time.

In recent years, several collaborative spaces for engineering education have been developed. Examples of these are some virtual laboratories for knowledge sharing, available in Internet, where a graphical environment is created to simulate physical processes, such as the control systems described by Villar-Zafra et al. [1]. Advances in communications and computer technologies have made possible the remote operation of real experiments and, as a result, the implementation of web-based laboratories for different engineering fields. Particularly, remote laboratories for industrial automation training have been implemented such as the one described in [2], where a PLC is programmed to perform an industrial process. Computing tools are mainly used for the development of distance laboratories as the one where a combination of Simulink and Easy Java Simulations was employed to remotely carry out an experiment [3]. Likewise, and perhaps most importantly, LabVIEW® virtual instrumentation is being widely used for the development of remote laboratories and e-learning spaces, becoming a powerful resource to this aim. This can be confirmed by looking at the work described by Hasim et al. [4], where LabVIEW® software is the primary tool used.

Following the outcomes of recent work on the development of a web-based laboratory for the remote access and automation of an AC motor [5] and trying to provide experimental training to a larger amount of students in a public university with five campuses, sharing the available resources among them, the development and implementation of a remote laboratory for training on industrial automation is presented in this paper. This laboratory was developed using LabVIEW® virtual instrumentation and it allows the remote control of an electropneumatic system that represents an industrial process.

2. Description of the system

2.1. Overall structure

The general outline of the developed system is shown in Figure 1. An electropneumatic circuit is actually connected at the laboratory. The experiment is controlled through a computer and the control and monitoring is available through the Internet.

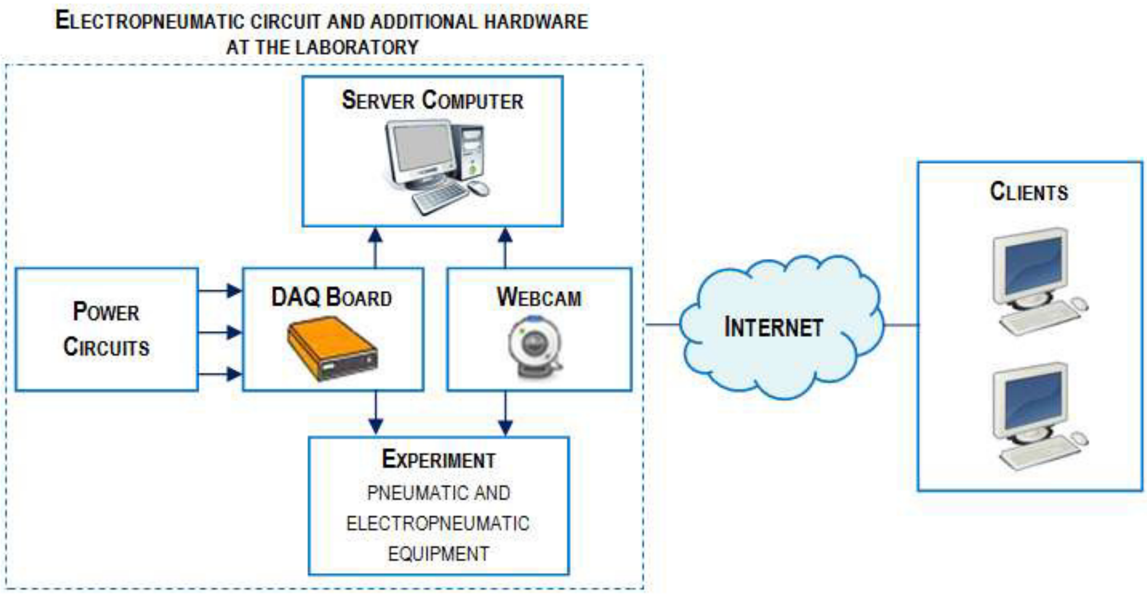


Fig. 1. Overall outline of the remote laboratory developed.

Besides the laboratory equipment needed for the connection of the electropneumatic circuit, additional hardware is required, namely a data acquisition (DAQ) board, power circuits, a webcam and a personal computer equipped with LabVIEW® software so as to replace manual operation and to be able to remotely perform the experiment. Both the DAQ board and the camera are connected to USB ports of the computer.

Virtual instrumentation was developed using LabVIEW® software to perform every required task of the industrial process represented by the electropneumatic system. The virtual instruments execute at the server computer and allow the control of several parameters, show graphical indicators of the process and display images of the real laboratory equipment.

The remote access and operation of the experiment over the web was carried out employing the LabVIEW® web server and the *Web Publishing tool*, also available within the LabVIEW® software. The use of these features allows publishing the front panel of the developed virtual instruments on a web browser so that users (clients) can control the electropneumatic experimental system over the Internet from anywhere.

2.2. Electropneumatic system description

The proposed experiment to be remotely performed in the web-based laboratory is the control of an electropneumatic system, which represents an automated industrial process for stamping of parts. The electropneumatic circuit consists of two double-acting cylinders, each one controlled by an electrically actuated valve with spring return and 5 ways-2 positions. A third of these valves, working as a 3 ways-2 positions valve (an outlet port was blocked) is used to supply compressed air to the pneumatic system. Two flow control valves were also employed to restrict the air flow in the advance of each cylinder.

Regarding the electrical part of the circuit, a total of four proximity sensors (either inductive or capacitive) were placed to detect the position (retracted or extended) of the piston rod for each cylinder. The output signal of the sensors will be 24 VDC when the sensor is detecting the piston rod, otherwise the electrical signal will be 0 V. The electrically actuated valves will be also activated when they receive a 24 VDC signal.

The electropneumatic system must follow a motion sequence so as to execute the stamping process. In the represented process, the parts to be stamped are initially stored in a magazine. Cylinder A (first cylinder) has the function to push the parts out of the magazine and to place them in order to be stamped by the second cylinder (cylinder B). Initially, both cylinder piston rods are retracted (the two sensors for this position are activated). When a *start* button is pressed, cylinder A advances placing the part by pushing it through a platform and the sensor of the extended position of the first cylinder is activated. Once cylinder A has advanced (the part is now in the right place), cylinder B extends and stamps the part (sensor of the extended position for this cylinder is activated). After stamping the part, cylinder B returns immediately to its original position and the sensor for its retracted position is detected again. When this occurs, cylinder A retracts and a new part falls down by gravity from the magazine. At this point, the two cylinders have regained their initial positions and therefore, both sensors for the retracted position are detected and a timer is activated to count the drying time of the part. Once this time is reached, cylinder A extends placing again a new part in the right place while the already-stamped part is pushed out of the platform to a container and the whole sequence repeats.

3. Implementation of the virtual environment

For the implementation of the system in a virtual environment, a set of virtual instruments was developed using LabVIEW® software. Besides the virtual instrumentation, a data acquisition system is required in order to acquire the signals sent by the proximity sensors and, according to the programming sequence, to generate the signals that activate the control valves of the cylinders. With this aim, a DAQ board and power circuits for the inputs and outputs of the system were employed. A webcam was also incorporated to enable video communication with the laboratory, allowing monitoring of the experiment through the computer interface.

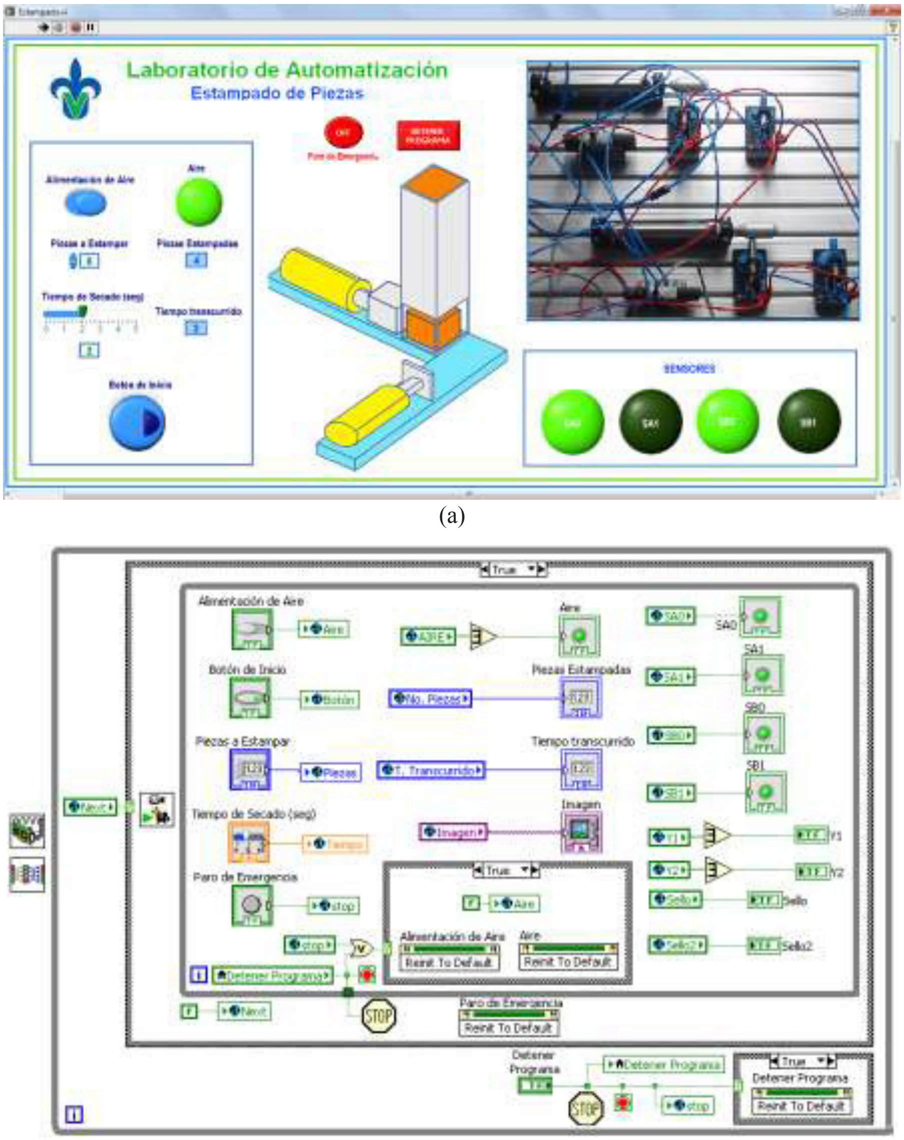
3.1. Virtual instrumentation

The front panel of the main virtual instrument is depicted in Figure 2(a). This is the virtual interface that the user interacts with. It consists of one numerical control to preset the number of parts to be stamped and a horizontal pointer slide to set the drying time. Once the number of parts and drying time are specified, the next step is to activate the *air supply* switch to provide compressed air to the pneumatic system. To begin the stamping process, the user must press the *start* button. The system will show through graphical indicators an animation of the stamping process according to the movement of the cylinder piston rods. The equipment installed at the laboratory can also be watched in real time through the image displayed at the top right corner. Indicative LEDs, placed at the bottom, show which proximity sensor is activated. An *emergency stop* button is also available so, when pressed, the air supply is deactivated and the process stops immediately.

The main programming code is shown in Figure 2(b), which is the corresponding block diagram of the main virtual instrument. It consists of three subroutines (subVIs) and several global variables. Each subVI has a specific function within the system: the virtual connection of the electropneumatic circuit, the control of the system, and the image acquisition. Global variables are used to pass and access data among these subVIs and the main virtual instrument, when they are running simultaneously.

When the program executes, it runs both the subVI for the control of the system and the subVI for the virtual connection of the circuit. These subVIs are shown as icons at the left side of the block diagram. The outer *while loop* is running as well, but the access to all controls and indicators placed in the front panel is conditioned by the global variable *Next*. Depending on the value *true* (T) or f*alse* (F) of this variable, this will run one of the two possible cases of the *case structure*. The state of this variable is determined by an output signal from the subVI for the virtual connection of the circuit.

As one important part of practical experimentation is to learn how to properly connect the equipment, a virtual instrument was developed to virtually make the connections required by the circuit, although the real equipment is actually installed at the laboratory. This virtual instrument was created so as to ensure that the user has the required knowledge to perform the experiment and to control the system. This subVI was configured in order to show its own front panel when called so that, when the program starts, the front panel of this subVI appears immediately (Figure 3 (a)). Each element used to connect the electropneumatic circuit at the laboratory is depicted in this front panel, which also consists of four buttons; three of them produce useful information about the system when they are pressed. Numeric controls and numbers were also added to this interface and each one of them was assigned to a given terminal of the pneumatic and electrical components.



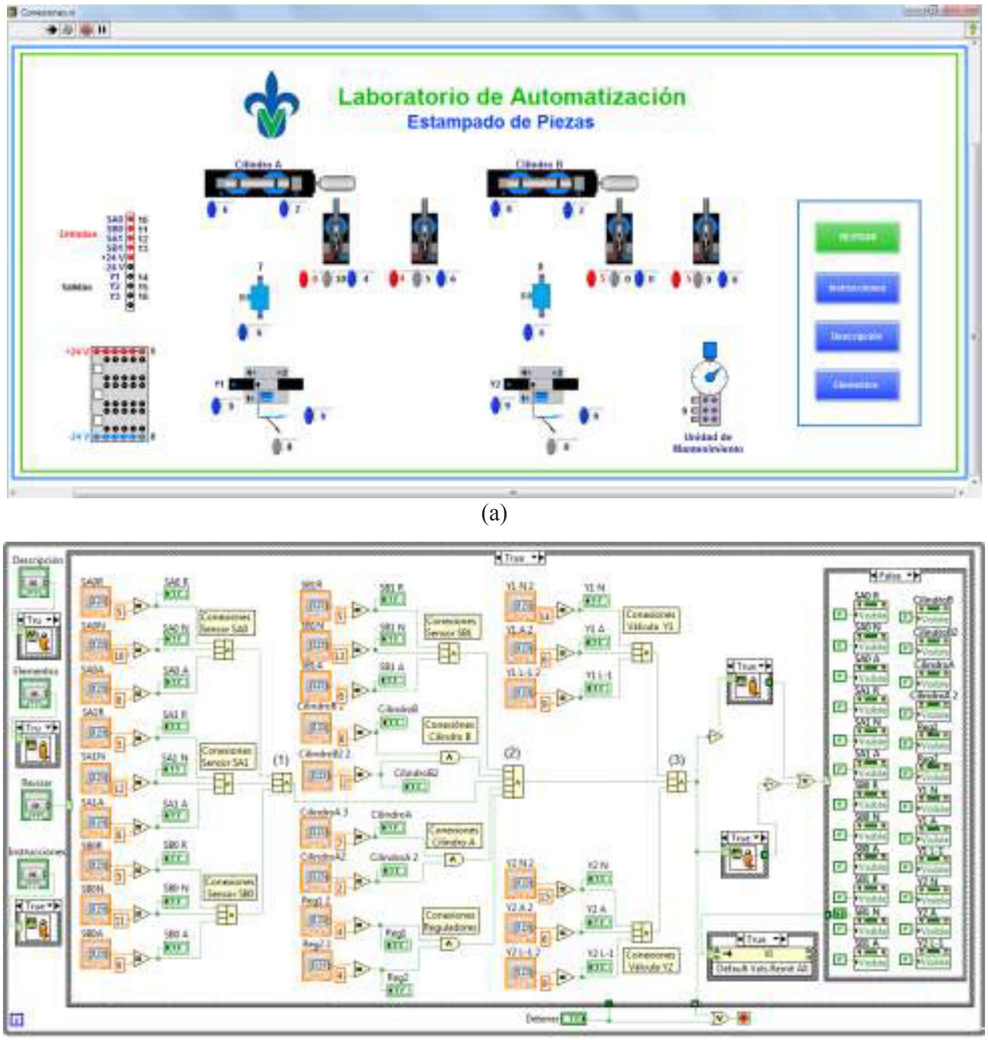
(a)

(b)

Fig. 2. Main virtual instrument for the implementation of the system: (a) front panel; (b) block diagram.

The user must connect those elements by introducing a number (terminal of a given element) in a numeric control (terminal of another component) pretending to be physically connecting the actual pair of terminals. Once the circuit is connected as explained, the user must press the *check* button in order to examine the connections, and then, some indicators will show whether the connections are right or wrong. Only when the entire circuit is properly connected, this front panel is closed showing again the main front panel.

The block diagram of this subVI is shown in Figure 3 (b). The value introduced into each of the numeric controls is compared to the correct value previously established. If these values are equal (correct connection), the comparison returns a logic 1; otherwise it returns a logic value 0. The output signals of the comparisons are sent to an AND logic function and thus, only when all connections are correct, the output of the AND function will be a logic 1. This output value is the one sent to the global variable *Next*, previously mentioned.



(a)

(b)

Fig. 3. Virtual instrument to virtually connect the electropneumatic system: (a) front panel; (b) block diagram.

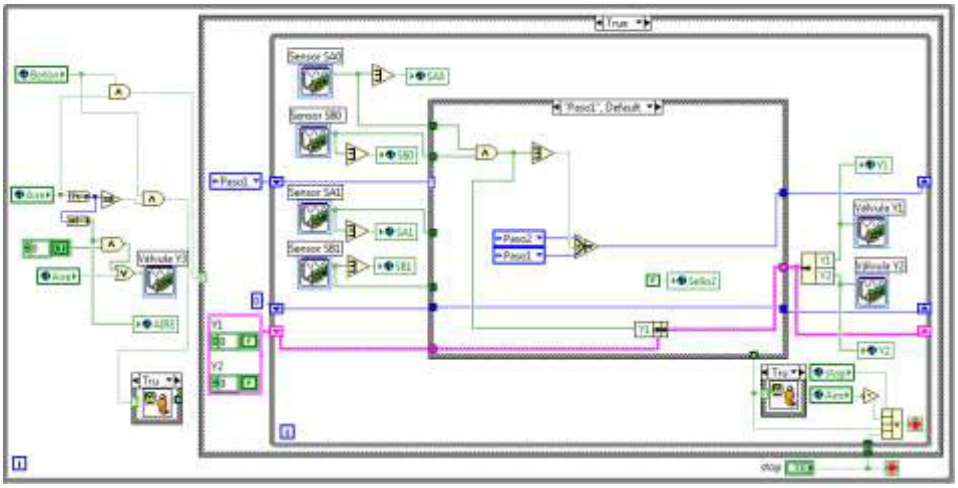


Fig. 4. Block diagram of the virtual instrument for the control of the electropneumatic system.

When the value of the global variable *Next* is a logic 1, the subVI for the image acquisition runs and the user gains access to the controls and indicators, as shown in Figure 2 (b). Data introduced in these controls are passed to the subVI for the control of the system through several global variables. Figure 4 shows the block diagram of this subVI. When the *air supply* button is pressed, a logic 1 is sent to the DAQ Assistant *Valve Y3*, which is sent as a digital output to one of the electrically actuated valves, providing compressed air to the system. The true case of the structure will execute only when the user press the *start* button and the air supply was previously activated. When this happens, the DAQ Assistants *Sensor SA0, Sensor SB0, Sensor SA1* and *Sensor SB1* begin to acquire the digital signals sent by the proximity sensors.

A *state machine* structure was used to execute the motion sequence of the cylinders. This structure consists of a *case structure* with six possible cases, corresponding to the stages of the stamping process. According to the activated sensors, a logic value is sent to the DAQ Assistants *Valve Y1* and *Valve Y2*, which generate a digital output for the respective control valve in order to activate it or deactivate it. An *Elapsed time* is used as the drying timer that will send a T value once the preset time has passed in order to run again the first case of the structure. A simple *increment* structure was used to build a counter, adding a numeric unit each time the sequence is completed. When the amount of required parts is equal to the number of completed sequences, the *while loop* inside the main *case structure* is finished and the stamping process stops. When the *stop* button is pressed, the outer *while loop* of the main virtual instrument is finished and the program stops execution.

The subVI for the image acquisition consists of the *Vision Acquisition Express VI* and an *image display*, both inside a *while loop*. The *Vision Acquisition* was configured by selecting the proper acquisition source and type (continuous acquisition with inline processing) so as to continuously acquire images of the equipment and display them in the front panel as a video. Details of the entire virtual environment are described in [6].

3.2. Data acquisition system

The data acquisition process was carried out using a 16-bit National Instruments USB-6211 multifunction DAQ board. The four digital input ports available in this board were used to acquire the signals sent by the proximity sensors. Three digital output lines were used in order to generate the signals to activate the control valves. Configuration of the input and output ports of the DAQ board was accomplished using the *DAQ Assistant Express VI* in LabVIEW® virtual instrumentation.

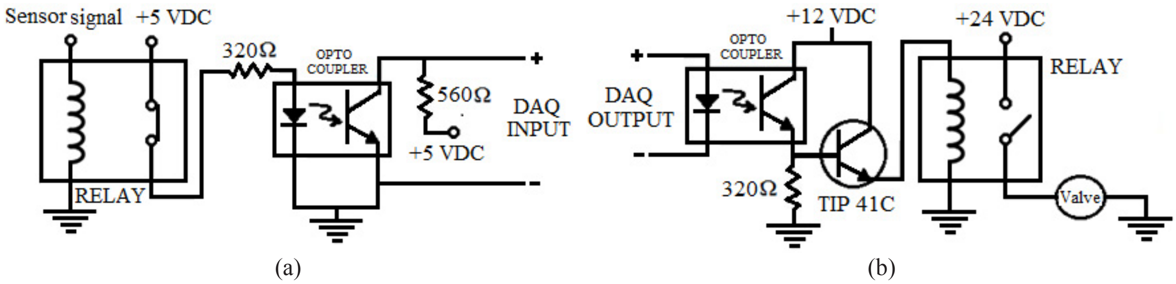


Fig. 5. Schematic diagrams of the power circuits for (a) digital inputs and (b) digital outputs.

The employed DAQ board does not support the current values sent by the proximity sensors and it neither manages the current required to activate the control valves. Therefore, a power circuit between the control section and the electropneumatic system is necessary. Two different power circuits (Figure 5) were mounted on a breadboard: one for the digital inputs and another one for the outputs. The power circuit for the digital outputs is similar to one previously reported in [5], and it will not be explained here. The power circuit for each digital input was constructed using a 4N26 optocoupler, a relay RAS 2410 for 24 VDC and 320Ω and 560Ω resistors. When a 24 VDC signal is sent by the sensor, it activates the relay opening its normally closed contact. When the contact is open, there is no current in the LED emitter and the phototransistor does not saturate so that the output voltage will be the 5 VDC taken from the DAQ board source. This current will be sent to the digital input port. If the sensor sent a 0 V signal, the contact remains closed, generating a current in the 560Ω resistor so the output voltage will be equal to zero.

4. Remote access operation

Previous works reporting the perception of students about the remote operation of engineering laboratories have shown that web-based laboratories are a powerful learning tool [7, 8]. How web-based laboratories have become an useful tool in research, enabling the shared use of resources and the effective collaborative schemes, can be noticed when reviewing the experience of students, as described by Santana et al. [9]. Moreover, since several years ago, remote laboratories have demonstrated pedagogical and educational benefits when comparing them with the conventional in-site laboratory approach [10].

Remote access, over the web, to the virtual environment was achieved employing the LabVIEW® web server. This server allows multiple users to access the front panel simultaneously and in real time, but only one of them can control it and perform the experiment at a time. The LabVIEW® web server must be enabled and configured on the server computer. To access the front panel through a web browser, the virtual instrument was published in a web page by creating an HTML file, using the *Web publishing tool*, available in LabVIEW® software. The server configuration and the HTML file creation were conducted in a similar way to that described in [5]. In this configuration, a time limit was set to determine how long a remote user can control the front panel. For the remote access to the front panel, LabVIEW® is not required but it is necessary to install the *LabVIEW Run-Time Engine* of the same version of the LabVIEW® software installed on the server computer. The *Vision Run-Time Engine* is also required to remotely view the displayed images.

The user accessing the front panel must request the control of the virtual instrument by right-clicking and selecting the option *Request Control of VI*. If there is no other user controlling the experiment, the control will be directly granted, but if another user has currently the control, the server queues the request and the control will be granted until the other user releases the control (right-clicking and selecting *Release Control of VI)* or the time limit is exceeded. Only the server user can regain control at any time and consult the users queue list.

5. Results and evaluation

The virtual environment for the control of the electropneumatic circuit was implemented both locally and remotely. To this aim, a conventional webcam and a NI USB-6211 multifunctional DAQ board connected to USB ports of a laptop computer with LabVIEW® software installed were used, as well as the previously described power circuits. The electropneumatic circuit was connected employing *FESTO Didactic* equipment, already available in the laboratory. Figure 6 shows the required equipment and the additional hardware for the experimental setup as installed at the actual laboratory.

First of all, the system was locally implemented and it worked as expected. The virtual instrument was executed and every available button in the main front panel was tested in order to verify their proper operation. The indicative lights and the graphical indicators worked correctly. The electropneumatic circuit performed the motion sequence correctly and the webcam acquired the images of the equipment displaying them in real time through the computer interface.

Once the functionality of the virtual environment was validated, a sample of students was selected in order to evaluate the remote operation of the system and find out what students thought about it. This evaluation was divided into two stages: first, the remote laboratory was tested by one student at a time and then, the remote operation of the system was simultaneously tested by the same students, located in different sites. As stated before, all of them could simultaneously access the experiment but only one had the control at a time. After the evaluations were completed, each student expressed his experience in using the remote laboratory.

In the first evaluation stage, the students performed remotely the experiment without any problems and they agreed that the entire operation of the system was successful. When comparing the learning achievements by using the remote laboratory with the traditional hands-on approach, students said that the virtual environment adds new features that make the experiment and the theoretical fundaments easier to understand, in addition to the schedule flexibility that the remote operation will provide. In general, the remote approach was well accepted by the students, who also suggested that it is a useful learning instrument with a friendly interface that makes it easy to use.

In the second evaluation stage, the students found some problems with the images streaming due to limitations imposed by the bandwidth at the local area network. They expressed that the simultaneous operation of the system prevented them from perform the whole experiment by their own and at their own pace. Although this situation limits their autonomous learning, they agreed that it is a powerful teaching tool since it permits real time demonstrations of the system to all the students.

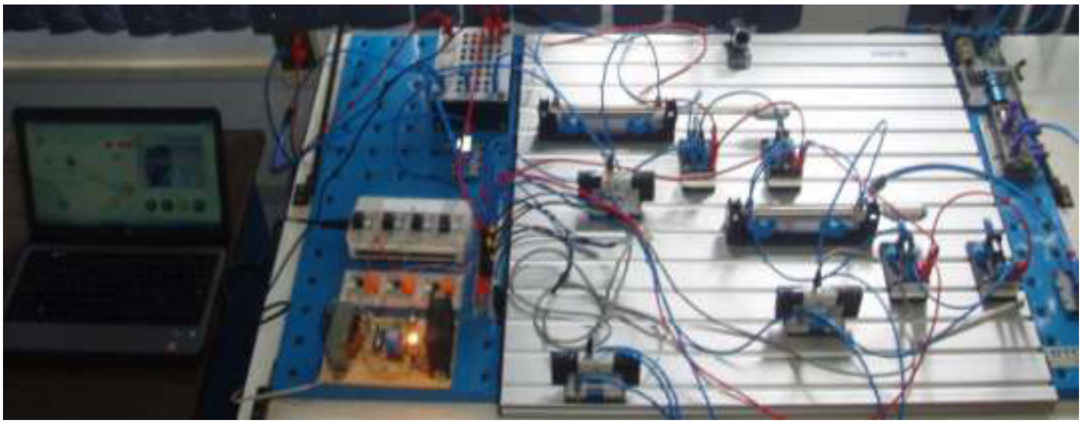


Fig. 6. Experimental setup: laptop computer, DAQ board and power circuits, webcam and electropneumatic circuit.

6. Conclusions and further work

The overall structure of a web-based laboratory for industrial automation learning has been presented. The system allows remote access over the Internet to a laboratory experiment, consisting in the control and monitoring of an electropneumatic circuit, which represents an industrial stamping process. For the implementation of the system, a virtual environment has been developed using LabVIEW® software and the laboratory equipment and additional hardware have been installed at the actual laboratory. Video communication with the laboratory has been incorporated and the experiment can be watched in real time through a computer interface. Remote operation of the experiment permits schedule flexibility, the shared use of resources and collaboration among different university campuses, giving access to experimental training to a larger amount of students, regardless their geographical location.

It is expected that the proposed experiment will soon be available through a web access system that permits registration of students and enables them to make reservations for usage of the experiment. Preliminary work on this access system has been previously reported [11]. The study on perception and experience of students about this remote laboratory is still in progress. The system will be integrated as part of the industrial automation course in the campuses where this course is offered and it will be tested not only by a random sample of students, but by all the students enrolled in the course. Aiming to improve the performance of the system, a poll is being conducted between students so as to deeper analyze the usefulness of the system and the pedagogical and learning achievements by comparing the obtained results with the traditional approach.

Future work is focused on the development of other experiments not only for the industrial automation web-based laboratory but also for other engineering fields such as electronics, mechanics, hydraulics and civil engineering, adding new features such as audio communication with the laboratory and the implementation of a virtual instrument for saving the video of the experiment to a file in order to watch it again later.

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