

Design and Structure of an Electronic Switching System for Remote Circuits Structuring and Online Measurements

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Abstract—This paper presents design and structure of an electronic switching system for remote circuits structuring through internet, where the possibility of building circuits from scratch while conducting electrical measurements at any point of built circuits by online experimenters. This switching system enables to interconnect between electrical and electronic components in different combinations of circuits while providing an online environment highly approximated to physical environments of traditional hands-on laboratories in terms of manipulating measurement instruments and building experimental circuits. This paper also presents results of deployed topology for remote exploit of this switching system along with results of its deployed online engineering experiments.

Keywords—online engineering experiment, online lab, remote experiment, remote circuit building

1 Introduction

During the global pandemic of COVID-19, virtual experiments and remote experiments through internet have been conceptually highlighted [1], [2] in terms of their contributing roles into supporting pedagogical aspects of educational establishments by providing practical courses to students while respecting the terms of public lockdowns and social physical distancing between individuals [3], [4]. Even though e-learning [5] and remote experiments [6] have been playing major roles in education and pedagogies of learning before the worldwide spreading of COVID-19, this pandemic highlighted them globally as reliable services and not only as supplementary to traditional education and traditional hands-on laboratory experiments.

Laboratories, or hands-on laboratories, have long been acknowledged as key element and indispensable integral component in engineering education. No one disputes the vital role of experimentation, particularly in engineering and applied science, in order for students to observe scientific phenomena, consolidate their understanding on theoretical concepts, and become more experienced with practical science [7], [8].

According to the published research in [9], it was reported that students retain 25% of what they hear, 45% of what they hear and see, and 70% if they use the “learning-by-doing” methodology, which is emphasized by the statements of ABET (Accreditation Board for Engineering and Technology).

According to ABET’s general criteria of accrediting baccalaureate level of engineering, practical skills are considered among essential studying outcomes that prepare graduates to attain the programmed educational objectives. However, in the literature, little attention has been paid to laboratory activities that are relevant to pedagogical topics [9].

During the early years, after the onset of formal engineering education, the focus was balanced between practice and theory. Overtime, the prevailing academic recognition criteria has shifted away from recognizing contributions to undergraduate education toward recognizing research productivity, which has drawn the attention away from cost, space, scheduling-encumbering, and time-consuming activities such as developing instructional laboratories.

Laboratories are generally costly in terms of necessary time and budget to develop, acquire, administrate, and maintain. They have extremely low overall utilization rates and limited usage beyond specific courses, and they are not often shared among universities despite the high cost of their used equipment. The current inflexible operation and constrained access to physical laboratories, in addition to the decreasing budgets and increasing in student numbers, all these factors have put pressure on universities toward providing effective practical laboratory environments to their students. This has been possible with the advent of online laboratories and the conveniences they provide.

Online laboratories are the laboratories that can be accessed and manipulated through internet. They are either virtual laboratories, remote labs or simulation-based laboratories.

Virtual laboratories are based on virtualized objects that rely on software products and web-based interfaces whereas exploiting simulation-based models of behaviors. These virtual labs provide shapes and illustrating objects highly approximated to physical instruments and used components in hands-on laboratories, without implicating physical equipment for experiments conduction.

Simulation-based laboratories are providing online experiments that rely on mathematical models, without offering virtualized objects and without implicating the use of physical equipment for experiments conduction.

Simulation is used in many contexts such as training, learning, and entertainment. During World War II, the “Link Trainer” flight simulator were used to improve safety and shorten training time for over 500 000 pilots; saving millions of dollars and many lives. In education, simulation is used for scientific modelling of systems to gain insight into their operations and behavior. It is a very useful tool especially for providing illustrations of phenomena in fields that are not easily visualized, such as electromagnetics, nanotechnology, chemistry, physics, and life science.

The differences between simulation-based laboratories and virtual labs are the levels of approximating the shapes, the dimensions and the manipulations of physical resources used during hands-on experiments.

In engineering, many simulation software and virtualization frameworks are available to be used for educational purposes of experiments or to be used at workplace, such as Simulink, National Instruments (NI) Multisim, PSpice, NI Ultiboard, CYME, PowerFactory, PS CAD and PowerWorld.

Early criticisms on computer simulations argued that these simulations are rigid, unrealistic, and do not adequately represent real-world systems and their behaviors. Consequently, today, it is generally agreed that neither computer simulations, nor virtualization, can completely replace hands-on laboratories, but they might be more effective when they are integrated as an adjunct to hands-on laboratories [7]. It may be also effective if we rely on hands-on laboratories as an adjunct to virtual labs, if these virtual labs provide high approximations to physical resources and provide similar results to the ones obtained during hands-on experiments.

Remote laboratories, on other hand, are based on real physical equipment, which are controlled, monitored, and manipulated through the internet. Remote laboratories have been shown to provide significant benefits comparing to traditional hands-on laboratories. Examples of these benefits include optimized and organized utilization, shared resources between institutions, versatile ranges of experimentation, mitigation of safety issues, in addition of providing more security and constrained access.

Remote laboratories appeared in the nineties; the idea was initially proposed in [7], [8], and two among their earliest reported implementations in education were presented at the papers [8], [9]. In the late nineties of 20th century, the release of the Internet server version (6i) of Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) [10], [11] by NI ignited the development and promulgation of remote laboratories among universities around the world. Consequently, LabVIEW framework is used in our nowadays by many universities to deploy remote labs.

Advocates of online laboratories outline the conveniences associated with their use in terms of cost mitigation, safety, flexibility, and optimization of utilization rate. Advocates of traditional hands-on laboratories argue that students should be exposed to real environments, which is consistent with the constructivism learning theory. However, proponents of remote laboratories might argue that nowadays-industrial processes are commonly automated and controlled remotely.

In a similar fashion, there are several questions, debates, and empirical comparative studies on whether remote or virtual formats of experiments are as effective as the traditional hands-on experiments [12-15]. For example, Corter et al. [12] found that online laboratories had an advantage in learning outcomes on simple experiments but not on the complex ones. Lindsay and Good [13] noted an existing substantial bias from students and general preference toward hands-on laboratories, with some potential for the other alternatives to be accepted. They also noted that students involved in the virtual laboratory group displayed a lesser grasp on the real context than those in the remote lab group and hands-on lab group. In turn, students involved in the remote lab group emphasized hardware objectives in their minds, while students involved in the virtual lab group emphasized theoretical objectives.

The general conclusion from these studies [12], [16] is that learning outcomes depend on the exact instructions given to groups and the different patterns of work and collaboration regardless of the laboratory format. Thus, provided scaffolding along

with laboratory assignment [17] and appropriate formation of laboratory groups [18] are major factors for learning outcomes. Nevertheless, deploying flexible remote experiments where the possibility of building circuits from beginning while providing the possibility of conducting measurements at any point of these circuits is attracting more attention of researchers, toward elaborating online environments for remote experimenting highly approximated to the environments of hands-on laboratories in terms of instruments manipulation and measurements conduction.

Starting from the nineties of twentieth century, there have been many published articles presenting various works of deploying [19], exploiting [20], [21], analysing [22], [23], and optimizing remote experiments and remote labs [24], [25]. Nevertheless, this paper is distinguished by presenting the design and structure of hardware and software parts of an electronic system (switching system, Figure 1), which enables the conduction of remote circuits structuring from beginning by interconnecting between electrical and electronic components from scratch whereas supporting measurements retrieving at any point of built circuits during remote experiments.



Fig. 1. Hardware resources of switching system and PXI

The structure of this switching system consists of multiple electronic cards dedicated either for components placing or measurements support, whereas relying on a product from National Instruments (PXI product) dedicated for measurements conduction and power supply by serving the functionalities of signal waves display, generation of electrical signal functions, retrieving measurements of voltage and current, etc.

The presented switching system in this paper along with PXI product enable to deploy an online environment (remote lab) for remote experimenting in electronics and electricity, while relying on different resources of software that manifest this online environment, which is highly approximated to hands-on laboratory environment in terms of instruments manipulation and circuits building.

This paper is structured as follow: Section 2, presents hardware design and structure of concerned switching system for remote circuits structuring. Section 3, presents design and components of software for remote circuits building and online measurements on this switching system. Section 4, presents results of deployed topology and deployed remote experiments using this switching system and PXI product. Finally, Section 5 for conclusion.

2 Design and structure of hardware

The use of the hardware parts of this developed switching system requires to purchase and install a whole-licensed version of LabVIEW platform for continued exploit. This platform must be installed with its integrity of hardware drivers, LabVIEW libraries and NI MAX (NI Measurements and Automation Explorer) for drivers' management; in order to install and use this developed switching system and the PXI product (Figure 1) with its instrument modules with no errors or latencies of misconfigurations.

2.1 Electronic switching system

This part of hardware, switching system part, is an extendable electronic system. It contains multiplicity of electronic boards developed according to a parallel architecture, Figure 1. It uses two bands of parallel branches to interconnect between its electronic boards, one band (Figure 2 part "a") of parallel branches to communicate the control data, and the second band (Figure 2 part "b") for electrical signal transfer between the electronic cards of this switching system.

Board number one of this switching system is dedicated for DC (Direct Current) power supplies and the support of generated functions, Figure 3. It contains a connection interface, interface "d" at Figure 3, to support the DC power supplies, which are generated by the PXI's DC power module. Each plug of these DC supplies is supported on this board interface through a wire port. Another connection interface on the same board, interface "e" at Figure 3, is dedicated to support the generated supply from the PXI's function generator module. In addition, this board consists of a USB port type B to communicate with the used computer machine for hosting, and consists of interface "a" at Figure 3 to supply the integrated processors on the switching system with electrical power.

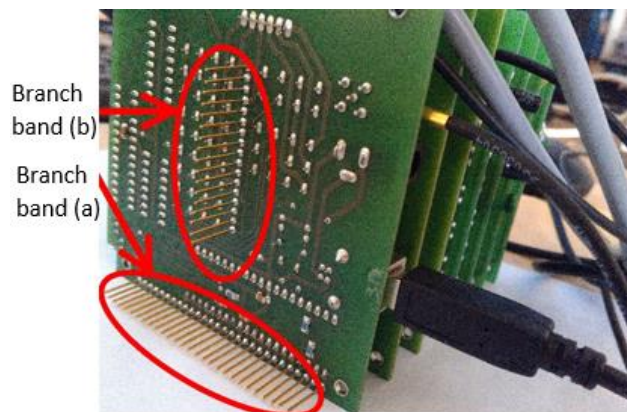


Fig. 2. Structure of parallel branch bands of switching system

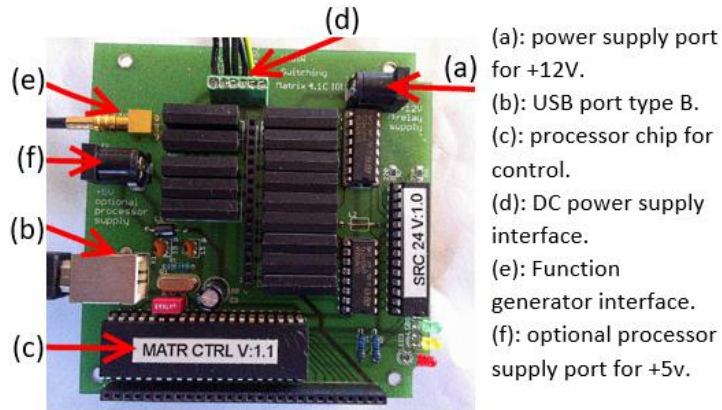


Fig. 3. Switching system's board number one; for power supplies

There are three used plug ranges of DC power supplies on this switching system; one range varies from 0V to +25V, other one from -25V to 0V, and the last one from 0V to +6V, plus the ground wire ports (0 V and commune port).

The presented switching system in Figure 1 consists of a Dual-multimeter board, Figure 4, with two ports as connection interfaces to support the measurements, which are conducted by the PXI's DMM module (Dual Multimeter Module). It also supports the switching between those two ports and the breadboard card's nodes (A, B, C, D, E, F, G, H and I) and nodes (0, com, X1, X2, X3, X4, X5 and X6) for measurements retrieving, Figure 6. The default-attributed number to this Dual-multimeter board is two.

The oscilloscope board of this switching system is shown in Figure 5, and it integrates two channel ports to support signal-retrieving processes, which are executed by the PXI's oscilloscope module. This board supports the switching functionality between the two oscilloscope channel ports and the breadboard card's wiring nodes (A,B,C,D,E,F,G, H and I) and nodes (0, com, X1, X2, X3, X4, X5 and X6), Figure 6, for signal retrieving. The default-attributed number to this oscilloscope board is three.

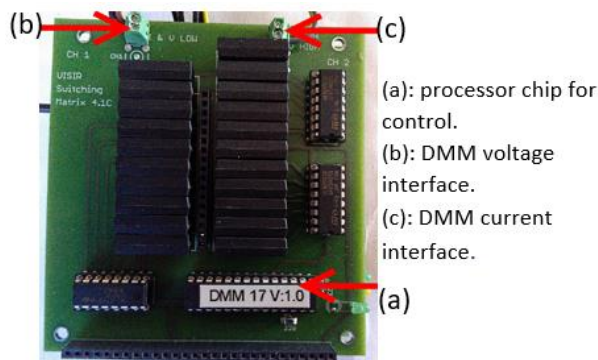


Fig. 4. Switching system's board number two, which is named as DMM (Dual-Multimeter) board

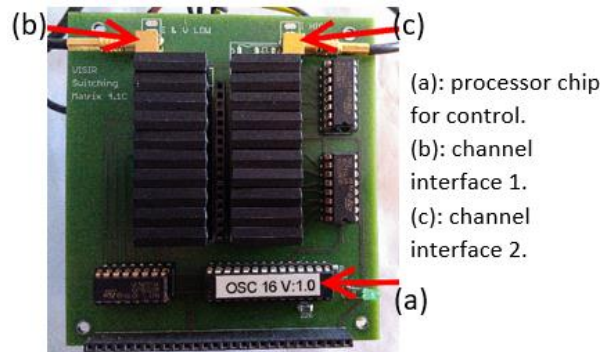


Fig. 5. Switching system's board number three, which is named as oscilloscope board

Breadboard card(s) of this switching system, principally named as components card(s), are dedicated to support the electrical and electronic components, which are placed for remote circuits structuring. Each breadboard card contains a number of electronic switchers to control the interconnections and wires between those components and the wiring nodes (A,B,C,D,E,F,G, H and I) and nodes (0, com, X1, X2, X3, X4, X5 and X6), Figure 6 part "a". Those breadboard cards contain the nodes (nX1, nX2, nX3, nX4, nX5, nX6, nX7, nX8, nX9, nX10, nX11, nX12, nX13 and nX14), Figure 6 part "b", for components placing. The nodes (A,B,C,D,E,F,G, H and I) and nodes (0, com, X1, X2, X3, X4, X5 and X6) are for the wiring of placed components, in order to circulate the generated electrical signals between the cards of the switching system and between the placed components.

The used switchers for components technical switching on shown switching system in Figure 1 are standing between the component nodes (nX1, nX2, nX3, nX4, nX5, nX6, nX7, nX8, nX9, nX10, nX11, nX12, nX13 and nX14), and the wiring nodes (A,B,C,D,E,F,G, H and I) and nodes (0, com, X1, X2, X3, X4, X5 and X6). The first breadboard card mounted on this switching system has the default number 4, and as many as added breadboard cards mounted on this switching system to place more components, their numbers are attributed successively by incrementing starting from number 4.

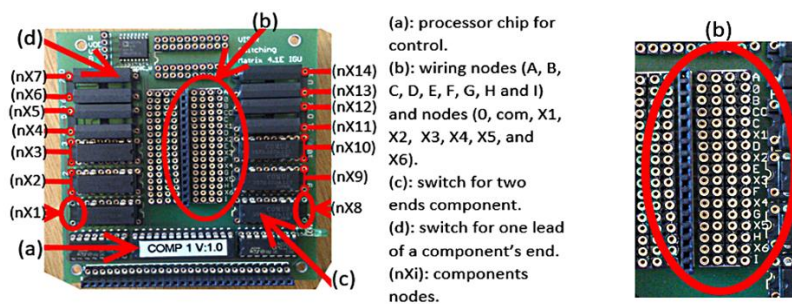


Fig. 6. Switching system's board number 4, which is named as breadboard card (components card)

The nodes (A, B, C, D, E, F, G, H and I) are considered as the principal wiring nodes due to their resiliency and flexibility to be used to lead and wire any component end, while offering the possibility of a wide range of manipulation and interconnection between these ends.

The node A is already related to the function generator interface through a two-state electronic switch on the function generator board; board number one. There is no possibility to, directly, switch or multiplex the generated function supply and redirect it to other wiring nodes, which means that any circuit aims to use the AC (Alternating Current) of power supply is forced to have its first component physically wired to the node A on the switching system.

There are also other nodes, named as (0, com, X1, X2, X3, X4, X5 and X6) at Figure 6 part “b”, which are in parallel with the principal wiring nodes and they are dedicated to support the DC power supplies and the ground branches (0V and com). Only the nodes (0, com, X1, X2 and X3) are technically enabled to wire the placed components on the breadboard card(s), whereas the other nodes (X4, X5 and X6) aim future extending of this switching system for new instruments of supply or measurements; otherwise, being adapted to be used as additional wiring nodes.

To elevate the number of placed components for experiments, it is necessary to add more breadboard cards to the switching system in parallel, because each breadboard card supports the use and control of, in maximum, ten components; as it is shown at Figure 6. The component nodes (nX1, nX2, nX3, nX8, nX9 and nX10) are for two-end components, whereas each one of the component nodes (nX4, nX5, nX6, nX7, nX11, nX12, nX13 and nX14) is for leading and connecting only one end of a placed component.

To establish a wiring connection between two components, they must be wired to the same wiring node; nodes (A, B, C, D, E, F, G, H or I) or nodes (0, com, X1, X2 or X3). In order to interconnect two different components placed on the same breadboard, two wires must be used to lead those components and connect them to the same wiring node. Otherwise, they must be wired to two similarly named wiring nodes on different breadboard cards; in case where the two components are placed on different cards. Those two cases are referred in the rest of this paper as direct wiring connection. Alternatively, it would be essential to use a shortcut wire to establish the connection between two different components wired to two different named wiring nodes, which is referred in the rest of this paper as non-direct connection. In another manner to reframe, each shortcut wire offers the possibility to circulate the electrical signal between two components connected to different named wiring nodes on any breadboard cards of the switching system.

The shown switching system in Figure 1 offers the hand on the building and measurements conducting on predefined circuits or their subcircuits. In addition, it offers the possibility of reusing a circuit component in other circuits in condition of having direct or non-direct wiring connections to their components; as previously described. Those offered possibilities of circuits building are handled by using a file with “max” as a file extension (max-files) for each supported experiment, in order to define the allowed components, the authorized types of power supply and setting the electrical limits of use.

2.2 PXI product and its instrument modules

PXI is a product of National Instruments (NI), and it supports different NI modules as measurement instruments similar to the usually used instruments in hands-on laboratories. There are many versions of these modules with different product serials. Therefore, as long as each used PXI module offers one of the following functionalities in this subsection, and all used modules are running under the same version of LabVIEW framework; the software of the switching system (Figure 1) will be able to exploit them.

The measurements conduction on presented switching system in Figure 1 relies on NI oscilloscope module (NI PXIe 5114) for electrical signal retrieving. NI DMM module (NI PXI 4070) for the measurements of current and voltage, in addition of retrieving the values of resistance, inductance and capacity of placed components on the switching system. NI function generator module (NI PXI 5402) for alternating power supplies in shape of functions: sinusoid, rectangular, triangle and tee. NI DC power supply module (NI PXI 4110) for DC power supplies: 0V to +25V plug range, 0V to +6V plug rang and -25V to 0V plug range.

Each one of these modules is under control by specific sub-VIs developed under LabVIEW framework. These sub-VI(s), plus the ones responsible of exploiting the switching system, are either in communication with the equipment server (Figure 8) or under its use, in order to exploit the shown hardware in Figure 1.

3 Design and components of software

Shown switching system in Figure 1 relies on two parts of software packages. The first part of these packages is the equipment server, which is responsible of the hardware control and measurements conduction on the physical built circuits. The second part includes the measurement server, which is dedicated for experiments monitoring and guiding, an online platform for identification, authentication and scheduling, and a web-user interface to serve a real approximated environment for circuits building nearly similar to the use of real breadboards and measurement instruments in hands-on laboratories.

3.1 Measurement server

The shown measurement server in Figure 7 listens on port 8080 by default, but the port value of this process is editable for changing. The principal function of this measurement server is to receive incoming connection sessions and incoming commands from each end-user of the web-user interface of the switching system, and then forwarding their principal contents to the equipment server through TCP/IP packets (Transmission Control Protocol/ Internet Protocol).

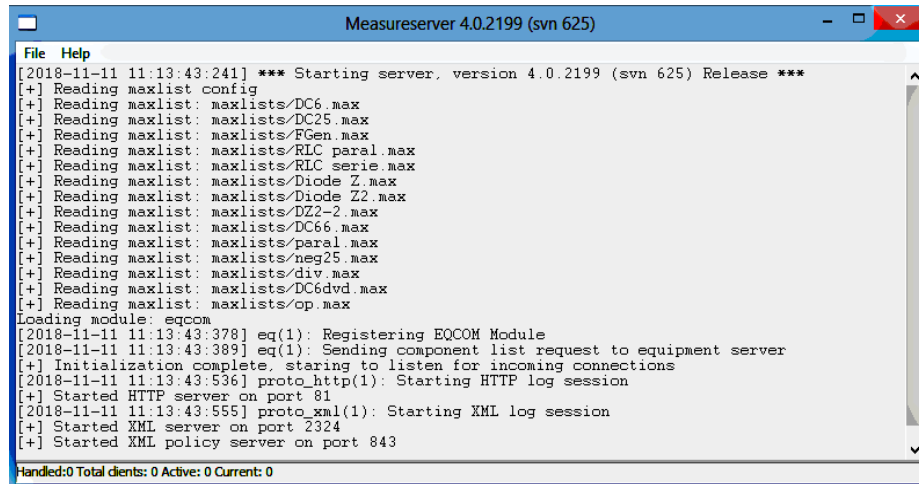


Fig. 7. Measurement server window while being running

This measurement server relies on a max-list file, which lists all max-files that describe the authorized experiments. Each authorized experiment must have its own max-file characterized by “max” as extension (experiment-name.max), in order to define the allowed components and supported power supply. For each file of these max-files, the user may build the entire predefined circuit or build only a subcircuit of it.

This measurement server receives the retrieved values of measurements from the equipment server through HTTP protocol (Hypertext Transfer Protocol). It uses the port 2324 as XML (Extension Markup Language) server’s listening port, and port 843 as listening port for XML policy server (Figure 7). It is developed under C++ programming language, since it is a powerful source to rely on for development and it is one of the principal programming languages considered by NI during their procedures of developing LabVIEW framework.

This choice of developing the measurement server under C++ programming language offers the advantage of using more resources of the hosting machine in functions of priority, allocated capacities of processors and RAM space (Random Access Memory). This advantage is resulted from the technical fact that, under C++ programming language, the measurement server functions as a service source code of the hosting machine; rather than using LabVIEW platform to create a version that will always function with limited priorities, limited allocated capacities of processing and limited space of RAM.

In the case of using LabVIEW platform for the development of the measurement server, this server would always function as an application coordinated under LabVIEW’s processes or its threads. This functioning scenario is considered as a limitation of LabVIEW programming platform, which is confronted by many researchers while experimenting on JIL server [26] to serve LabVIEW’s VIs through the internet.

3.2 Equipment server

This entity, equipment server shown in Figure 8, was developed under LabVIEW platform as a VI (Virtual Interface). It is in-charge of hardware control and experiments conducting by executing circuits building and measurements retrieving on built circuits, and then forwarding these measurement values to the measurement server. This equipment server uses the port 5001 to listen to the incoming connections and read the forwarded contents of commands and data from the measurement server, and then it answers the requests of experiments. It uses an equipment list-file to define the deployed PXI's instrument modules and the switching system, and it relies on a component list-file to define the placed components of electricity and electronics on the breadboard card(s) (components card(s)).

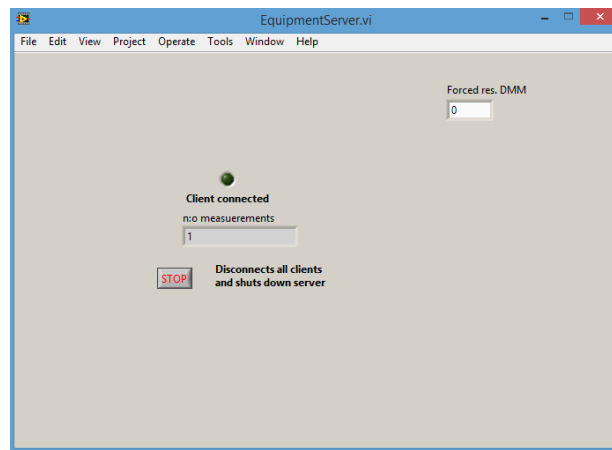


Fig. 8. Equipment server window while being running

When the equipment server executes the forwarded requests from the measurement server, it builds the requested circuits and retrieves the resulted measurements over a short varying slight of time, depending on the queried instruments and the types of measurements. Then, it releases the hardware resources, which offers the advantage of handling different connection sessions of experiments by serving nearly simultaneous requests of circuits building and measurements retrieving.

The limitation of using LabVIEW platform to develop this equipment server is; this entity will be always allocated with limited resources of RAM space and limited processing capacities of the hosting machine, without extreme high priorities of execution for higher allocation of resources.

This limitation is due to the fact that the equipment server will always work under LabVIEW's processes and its threads using limited allocated resources, while LabVIEW platform will be always treated at the level of running applications and running software on the hosting machine with many supplementary processing dependencies. Therefrom, the need to develop the measurement server under C++ programming language, in order to receive the incoming connections, managing the received commands

in a First In First Out waiting line (FIFO), and then forwarding them in form of simple requests to the equipment server by order of arrival. As a result, at this level of the communication scenario between the equipment server and the measurement server, the first one is in-charge of the execution of its incoming requests on port 5001, and then forwarding the retrieved measurements to the measurement server using HTTP protocol.

3.3 Web-user interface

This entity is an end-user web interface developed, principally, under HTML5 programming language (Hypertext Markup Language 5) and JavaScript (Figure 9). It contains a multiplicity of entities shaped in form of real measurement instruments, and a breadboard module similar in shape to the usual breadboards used in hands-on laboratories, which give more reality to the approximating environment of the switching system for practical experimenting (Figure 9). Each entity of them is related to a certain part of the hardware resources, either the switching system or the PXI's instrument modules: DC power supplies, DMM, function generator or oscilloscope.

The breadboard entity aims the aspects of components dragging and wiring for circuits building. The oscilloscope interface serves for electrical signals visualization at the inputs and outputs of built circuits during experiments. The DMM interface is dedicated to display the values of current, voltage, resistance, capacity and inductance. The function generator serves to configure the shape and amplitude value of the generated signal functions. The DC power entity is used to define the plug-range type and manipulate the value of generated DC power supply. The components library contains all supported components for circuits structuring, which are used to build the requested circuits during remote experiments (Figure 9).

3.4 Web-access platform

The access platform of this switching system is an online web-server platform for identification, authentication and reservation for experiments scheduling, and it is dedicated for the use of this switching system. It consists of multiple packages and parts as dependencies of software running:

1. Platform package. It is used to support all online services of identification, authentication and reservation. This package, basically, is a folder that contains all the scripts and program files, which are in-charge of handling the online sessions and supported services for the exploit of the switching system.
2. Web-user interface package. It is used for components dragging and wiring for circuits building, where the need to define a new path-link to this package folder, in order to be recognized by the used server system.
3. Smarty 2.6.30 package. It is used to support the handling of online web pages: creation, edition and manipulation.
4. PEAR service package (PHP Extensions and Applications Repository), used to support extensions and libraries of PHP (Hypertext Preprocessor).

- Open SSL (Secured Socket Layer) service package, or any commercial SSL packages or certificates, in order to use secured data sessions under HTTPS protocol (Hypertext Transfer Protocol Security).

4 Results of deployed topology and remote experiments

After installing the hardware and software parts of the switching system. Placing electrical and electronic components for the aimed experiments of circuits structuring on the breadboard cards of this switching system. Declaring and defining these components in the components list-file used by the equipment server. Declaring the authorized and supported circuits for structuring as max-files to be used by the measurement server. Editing the max-list file to refer the names and paths of all experiments max-files, and editing the library list-file used by the web-user interface to define the available component shapes for dragging, manipulating and wiring. Finally, we adapted the hosting server of the switching system to the network of our remote laboratory. The resulted topology of deployed resources of software and hardware of the switching system in our remote lab is as shown in Figure 9.

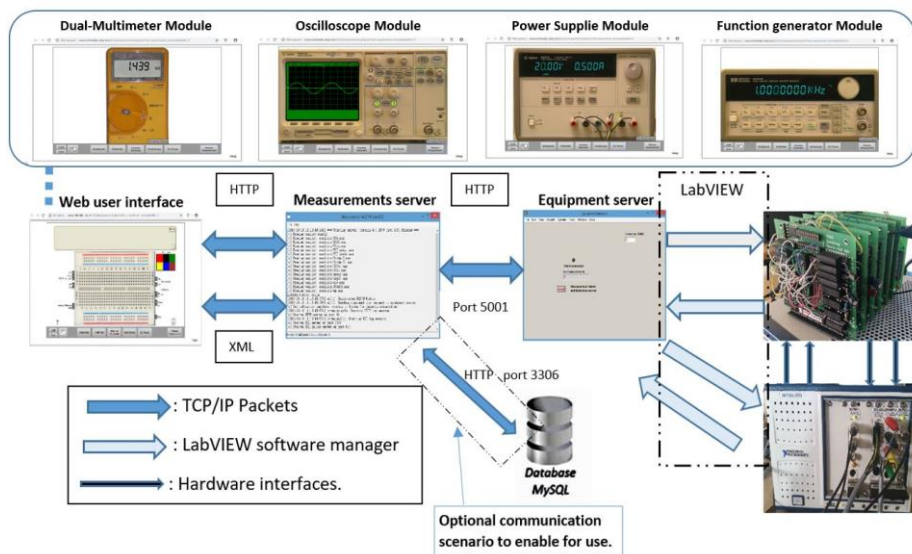


Fig. 9. Deployed topology of hardware and software for remote circuits structuring and online measurements on the switching system

LabVIEW framework is responsible of handling the communication between the equipment server and the hardware resources, whereas the communication between equipment server, measurement server and web-user interface are handled through HTTP protocol.

There is an optional communication scenario to use for authentication (Figure 9) where the measurement server is configured to check the database for each incoming experiment session, in order to verify whether it is authorized to occur and be served at that time or not.

The results of deployed remote experiments on shown deployed topology in Figure 9 include online experiments on electrical components, electronic components, motors and 3-phases generators, which are as shown in Figure 10 and Figure 11.

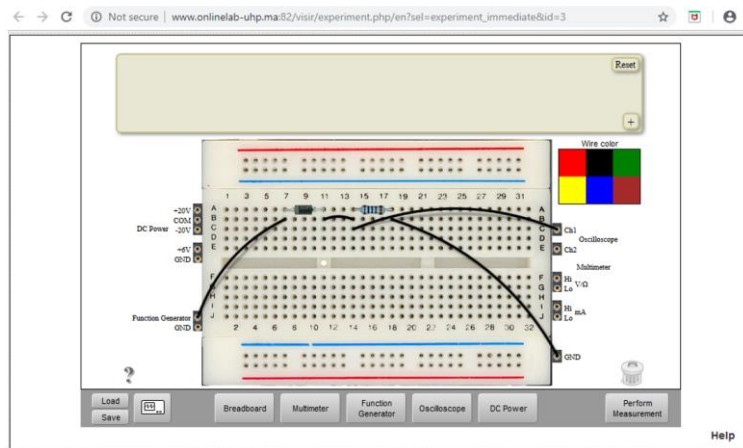


Fig. 10. Online experiment on a diode and a resistor

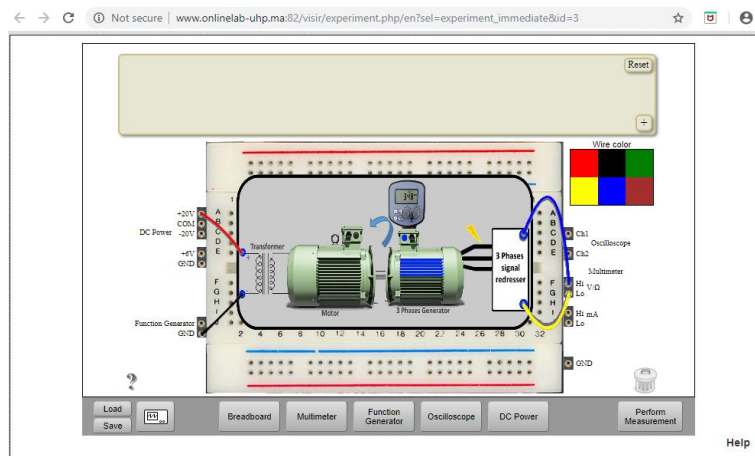


Fig. 11. Online experiment on a motor and a three phases' generator

5 Conclusion

This paper presents the design and structure of hardware and software parts of an electronic switching system that enables the building of analogue circuits remotely, whereas opening the way to conduct online measurements on these circuits at any point. This switching system provides an online environment for experimenting highly approximated to hands-on laboratories in terms of circuits building, instruments manipulation and measurements conduction. The hardware and software parts of this switching system are deployed according to a remote lab network, and they support online experiments on electrical component, electronic components, motors and three-phase generators.

6 References

- [1] Bangert, K., Bates, J., Beck, S. B. M. (2020). Remote practicals in the time of coronavirus, a multidisciplinary approach,” *Int. J. Mech. Eng. Educ.*, 1-21.
- [2] Gamage, K. A. A., Wijesuriya, D. I., Ekanayake, S. Y. (2020). Online Delivery of Teaching and Laboratory Practices: Continuity of University Programmes during COVID-19 Pandemic, *Education Sciences*, 10: 291-298. <https://doi.org/10.3390/educsci10100291>
- [3] Daniel, S. J. (2020). Education and the COVID-19 pandemic, *Prospects*, 49: 91-96. <https://doi.org/10.1007/s11125-020-09464-3>
- [4] Adedoyin, O. B., Soykan, E. (2020). Covid-19 pandemic and online learning: the challenges and opportunities, *Interactive Learning Environments*, 1-13. <https://doi.org/10.1080/10494820.2020.1813180>
- [5] de Oliveira, M. S., Penedo, A., Pereira, V. S. (2018). Distance education: advantages and disadvantages of the point of view of education and society, *Dialogia*, 139-152. <https://doi.org/10.5585/dialogia.N29.7661>
- [6] Mtebe, J., Raphael, C. (2018). Key factors in learners’ satisfaction with the e-learning system at the university of dar es salaam, Tanzania, *Australasian Journal of Educational Technology*, 43: 75–86. <https://doi.org/10.14742/ajet.2993>
- [7] Antsaklis, P., Baqar, T., DeCarlo, R., McClamroch, N. H., Spong, M., Yurkovich, S. (1999). Report on the nfs/css workshop on new directions in control engineering education, *IEEE Control Systems Magazine*, 53–58. <https://doi.org/10.1109/MCS.1999.793442>
- [8] Antsaklis, P., Basar, T., DeCarlo, R., McClamroch, H., Spong, M., Yurkovich, S. (1998). NSF/CSS workshop on new directions in control engineering education, Technical Report, University of Illinois at Urbana-Champaign.
- [9] Aström, K. J. (1999). *Advances in control: Highlights of ECC’99*, London, Springer, 1–28.
- [10] khazri, Y., Sabri, A., Sabir, B., Toumi, H., Moussetad, M., Fahli, A. (2017). Remote Control Laboratory Experiments in Physics using LabVIEW, *International Journal of Information Science and Technology*, 1: 11–16.
- [11] Muhammad Asraf H., Nur Dalila K.A., Zakiah M.Y., Amar Faiz Z.A., Nooritawati M.T. (2018). Computer Assisted E-Laboratory using LabVIEW and Internet-of-Things Platform as Teaching Aids in the Industrial Instrumentation Course, *International Journal of Online and Biomedical Engineering*, 14: 26-42. <https://doi.org/10.3991/ijoe.v14i12.8992>
- [12] Corter, J. E., Nickerson, J. V., Esche, S. K., Chassapis, C., Im, S., Ma. J. (2007). Constructing reality: A study of remote, hands-on, and simulated laboratories, *ACM Transactions on Computer-Human Interaction (TOCHI)*, 14: 7. <https://doi.org/10.1145/1275511.1275513>

- [13] Lindsay, E. D., Good, M. C. (2005). Effects of laboratory access modes upon learning outcomes, *IEEE Transactions on Education*, 48. <https://doi.org/10.1109/TE.2005.852591>
- [14] Chiu, J. L., DeJaegher, C. J., Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties, *Computers & Education*, 85: 59–73. <https://doi.org/10.1016/j.compedu.2015.02.007>
- [15] Colbran, S., Schulz, M. (2015). An update to the software architecture of the ilab service broker, in: *Remote engineering and virtual instrumentation international conference, (REV)*. <https://doi.org/10.1109/REV.2015.7087269>
- [16] Esposito, G., Mezzogori, D., Reverberi, D., Romagnoli, G., Ustenko, M., Zammori, F. (2020). Non-Traditional Labs and Lab Network Initiatives: A Review, *International Journal of Online and Biomedical Engineering (iJOE)*, 16: 14-13.
- [17] Regina-de-Carvalho, L., Évora, Y. D. M., Zem-Mascarenhas, S. H. (2016). Assessment of the usability of a digital learning technology prototype for monitoring intracranial pressure, *Revista Latino-Americana de Enfermagem*, 24. <https://doi.org/10.1590/1518-8345.1054.2777>
- [18] Heradio, R., de la Torre, L., Dormido, S. (2016). Virtual and remote labs in control education: A survey, *Annual Reviews in Control*, 42: 1–10. <https://doi.org/10.1016/j.arcontrol.2016.08.001>
- [19] Kreiter, C., Klinger, T. (2020). Development of a Low-Cost Remote Lab Concept for Electronic Engineering Education Based on NI myDAQ and NI ELVIS, *International Journal of Online and Biomedical Engineering (iJOE)*, 16: 18–29. <https://doi.org/10.3991/ijoe.v16i14.17007>
- [20] Najimaldeen, R., Ribeiro, G., Pedro, A., Gustavsson, G. I. (2016). Using uml models to describe the visir system, *International Journal of Online Engineering*, 12: 310–318. <https://doi.org/10.3991/ijoe.v12i06.5707>
- [21] Alves, G. R., Fidalgo, A., Marques, A., Viegas, C., Felgueiras, M. C., Costa, R., et al. (2016). Spreading remote lab usage a system—A community—A Federation, *Proceedings of 2nd International Conference of the Portuguese Society for Engineering Education (CISPÉE)*, IEEE. <https://doi.org/10.1109/CISPÉE.2016.7777722>
- [22] Garcia-Zubia, J., Cuadros, J., Romero, S., Hernandez-Jayo, U., Orduña, P., Guenaga, et al. (2017). Empirical analysis of the use of the visir remote lab in teaching analog electronics, *Journal of IEEE Transactions on Education*, 60: 149–156. <https://doi.org/10.1109/TE.2016.2608790>
- [23] Hernandez-Jayo, U., Garcia-Zubia, J., (2016). Remote measurement and instrumentation laboratory for training in real analog electronic experiments, *Journal of Measurement*, 82: 123-134. <https://doi.org/10.1016/j.measurement.2015.12.017>
- [24] Manuel, B. M., Alejandro, M. A., Pablo, B. A., et al. (2019). Use of VISIR Remote Lab in Secondary School: Didactic Experience and Outcomes, in *Smart Industry & Smart Education, Lecture Notes in Networks and Systems*, Springer, Cham.
- [25] Viegas, C., et al., (2018). Impact of a remote lab on teaching practices and student learning, *J. Comp. Educ.*, 126: 201–216. <https://doi.org/10.1016/j.compedu.2018.07.012>
- [26] Chacón, J., Vargas, H., Farias, G., Sánchez, J., Dormido, S. (2015). EJS, JIL Server and LabVIEW: An architecture for rapid development of remote labs, *IEEE Transactions on Learning Technologies*, 8. <https://doi.org/10.1109/TLT.2015.2389245>

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