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VISIR Remote Laboratory: The Switching Matrix Limitations

Frederico L. Jacob
Physics Department
Instituto Superior de Engenharia do Porto (ISEP)
Porto, Portugal
ORCID: 0000-0002-0912-2245

André V. Fidalgo
Electrical Engineering Department
Instituto Superior de Engenharia do Porto (ISEP)
Porto, Portugal
ORCID: 0000-0003-1219-3105

Elio San Cristobal Ruiz
Electrical Engineering, Electronics, Control, Telematics and Applied Engineering Chemistry Department
Universidad Nacional de Educación a Distancia (UNED)
Madrid, Spain
ORCID: 0000-0003-2102-977X

Felix Garcia Loro
Electrical Engineering, Electronics, Control, Telematics and Applied Engineering Chemistry Department
Universidad Nacional de Educación a Distancia (UNED)
Madrid, Spain
ORCID: 0000-0001-5445-2377

***Abstract*—In a rapidly evolving world, technology plays a fundamental role in transforming the way students learn and interact with theoretical and practical concepts. A striking example of this progress is the Virtual Instrument Systems in Reality (VISIR), a popular remote laboratory platform developed for teaching specific subjects such as analog electronics and electricity. This laboratory allows students to conduct practical experiments over the internet, potentially using real equipment, installed in a distant location, and controlled remotely. Therefore, students can access the VISIR remote laboratory through a web browser and interact with instruments and circuits as if they were in a conventional laboratory. However, probably because it has not received any relevant updates for quite some time, this platform presents several limitations, which will be explored in this paper, essentially those currently existing in the Switching Matrix. This approach was based on information published in scientific literature combined with feedback from intensive user and owner experiences. This evaluation aims to identify various weaknesses (technical, educational or pedagogical, operational, and economical) of the Switching Matrix, which may be considered threats to the future of the VISIR remote laboratory and affect its performance and stability, as well as its expansion to a wider community of users. It should be noted that suggestions for solutions to correct the limitations of this part of the remote platform are not given.**

Keywords—Limitations, Switching Matrix, VISIR

I. INTRODUCTION

According to [1], the VISIR remote laboratory is the most popular experimentation platform in the teaching of electrical circuits and analog electronics, and it was at the forefront of a worldwide movement in the field of distance practical teaching. Thus, in addition to being a physical measurement device, this platform is also an educational instrument that, in accordance with the authors of [2], is so widespread that the bibliography (conference proceedings, journal articles, theses, book sections, etc.) focusing exclusively on this laboratory amounts to about three hundred publications.

The VISIR remote laboratory, as shown in Fig. 1, is essentially comprised of a physical unit consisting of various hardware and software components [3], communicating with students through a web interface, namely, a virtual breadboard where all the necessary components for conducting experiments are available [4]. Thus, this platform is divided into three main blocks, namely, the experimental setup (Switching Matrix, PXI chassis and its modules, etc.), the servers (Web Server, Equipment Server, and Measurement Server), and the client (which provides access to and interaction with available experiments).

Fig. 1. VISIR remote laboratory platform [4]

The Switching Matrix of the VISIR remote laboratory is a remotely controllable circuit wiring manipulator consisting of a stack of Printed Circuit Boards (PCB), specifically designed for this platform [3]. Therefore, this device plays a fundamental role in configuring and interconnecting components (transistors, op-amps, electrical resistors, capacitors, etc.), shortcut wires, and instruments used in experiments. In other words, circuits are created by adding or removing components and shortcut wires directly on the multiple boards, while signals and/or electrical voltages, as well as measurements, are obtained by connecting them to the modules of the PXI chassis. While offering flexibility for students to explore a wide range of circuits and phenomena, adapting to the specific needs of each experiment, the Switching Matrix does, however, present some important limitations.

The VISIR remote laboratory has been used daily in various academic research projects and multiple classes worldwide, thus requiring it to be always fully operational. However, despite some development efforts, the lack of a long-term design strategy results in lingering inconveniences that remain unresolved, are not fully identified, or are only partially addressed. This applies to all elements composing this experimentation platform. Therefore, the focus of this article is to evaluate the functioning of the Switching Matrix, one of the most important components of the VISIR remote laboratory, and subsequently identify the various limitations it currently faces. Thus, this work consists of describing the limitations of the Switching Matrix and explaining, if possible, how they influence the performance of the remote platform, the preparation of experimental activities, and/or the results obtained in experimentation.

This document is divided into four distinct sections. In the following section (Section II), the Switching Matrix is briefly described. Then, in Section III, considering information published in the literature (articles, theses, etc.), as well as the feedback from users and owners of the VISIR remote laboratory, the main limitations of the Switching Matrix that have already been identified are presented. These limitations are grouped into distinct categories, that is, technical, educational or pedagogical, operational, and economical, and are characterized and shortly explained. Conclusions are presented in the last section (Section IV).

II. VISIR Switching Matrix

In the VISIR remote laboratory, the Switching Matrix, specifically designed for this platform, is responsible for interconnecting components and shortcut wires together, and connecting instruments to the circuit to enable the introduction of signals or electrical voltage and to perform measurements. Thus, this linking mechanism replaces the user manipulation of physical laboratory devices, which is often the most complex part of a remote laboratory [4].

Designed, conceived, and commercialized by *Blekinge Tekniska Högskola* (BTH) [1], the Switching Matrix, as shown in Fig. 2 (with only one Component Board), contains distinct types of boards. Consequently, it has boards for allocating the components used in experiments (Component Boards), boards for connection to instruments (Instrument Boards), and other boards for connection to DC power supplies and signal sources (Source Board) present in the modules of the PXI chassis. In addition to these, there are also Dual Component Boards that allow for free connection between nodes of up to two components with two terminals each, or a low-frequency instrument, such as a digital multimeter. To expand the range of applications, there is also the possibility of externally connect the Component Boards of the Switching Matrix to other components (for example, with a different pinout to the one supported by the platform) or boards containing implemented complex circuits.

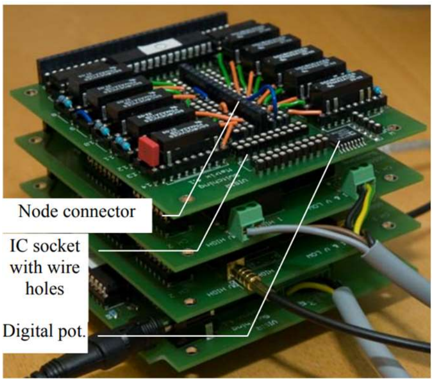

Fig. 2. Switching Matrix [5]

The Component Boards of the Switching Matrix consist of a microcontroller (the Board Controller), the Microchip PIC16F767, whose purpose is to identify each board, deals with the message format, and control the components included in it, several electromechanical relays, a 10 kΩ digital potentiometer, two ULN2003A (a seven Darlington array) chips, various sockets for components and shortcut wires, and bus connectors for communication between the various boards.

The Instrument Boards come in two distinct types, that is, the DMM Board (for voltage, electrical resistance, and current intensity measurements) and the Oscilloscope Board. Both types include the Board Controller and bus connectors, and, additionally, they have specific pins allowing measurement inputs to be connected to any node of the platform.

The Source Board is unique for each Switching Matrix and allows connection to various power sources, such as the function generator and DC power supply, present in the modules of the PXI chassis. It also has an external connection to a 12 V_{DC} source used to power the electromechanical relays. Additionally, this board is used to transmit control signals between various parts of the platform, hence it includes a dedicated microcontroller for this task (the Matrix Controller), the Microchip PIC18F4550 [5].

In addition to these connections with the PXI chassis modules, the Switching Matrix communicates with the computer containing the various servers via a USB cable, facilitating the internet connection that enables students to conduct the practical experiments.

The Equipment Server, entirely developed in Laboratory Virtual Instrument Engineering Workbench (LabVIEW), a graphical programming language from National Instruments (NI), controls the Switching Matrix, allowing it to execute and implement the circuit created by the student and provide measurement results [6]. Thus, among other functions, it manages the execution of student commands without directly communicating with them, receiving orders from the Measurement Server and accessing the Component List, a file used to describe all components, their nominal values, the possible connections, and their exact positions in the Switching Matrix.

III. Switching Matrix limitations

In [7], the authors mention that there are many weaknesses of diverse types in the VISIR remote laboratory, indicating that several aspects need improvement as they could be seen as a threat to its existence, even in the near future.

The third-party dependence of the VISIR remote laboratory, including the Switching Matrix, is the biggest limitation of this platform, causing difficulties of various sorts, such as the impossibility of easily using hardware from different manufacturers.

Considering all the information published in scientific literature (articles, theses, etc.) and feedback from intensive user and platform owner experiences, limitations related to the Switching Matrix can be divided into technical, educational or pedagogical, operational, and economical categories, and are presented in the following sections.

A. Technical limitations

One of the main technical limitations of the Switching Matrix is that it only allows circuits with up to eight nodes. However, since the output of the signal generator is internally connected to node A, when this instrument is used in the circuit, the number of available nodes is further limited. As all components and shortcut wires are always connected to a node, the design of the experimental setup becomes more complex than with a standard breadboard in a conventional laboratory [8].

The Switching Matrix has limitations regarding the storage capacity of components and shortcut wires because, at most, only 15 Component Boards can be stacked together [9]. Therefore, components need to be frequently changed to match those required to implement the circuits, which limits the number of experiments that can be conducted simultaneously by students [10].

According to [11], an important limitation is the physical impossibility of directly connecting one installed component to another existing on the Component Boards. It is also observed that this is related to the MaxList files (as example, a part of one in Fig. 3) because, essentially, they represent a logical barrier to direct combinations between two or more components, installed in the same or another Component Board.

```
VFGENA_24_1 A 0
VDCCOM_24_2:1_11 0
VDC+25V_24_4:1_13 B
VDC-25V_24_5:1_12 C

R_3_1 E G 10k
R_4_1 A H 150
R_4_2 A H 270
R_4_3 B E 47k
R_4_8 B E 56k
R_4_9 D E 10k
R_4_10 H I 10k
R_13_6:13_7 F H 10k_X

OP_4_6:4_5:4_14:4_13:4_7 NC1 D I C NC2 F B NC3 uA741

SHORTCUT_1_5 D E
SHORTCUT_3_4 E G
SHORTCUT_3_12 H I
SHORTCUT_24_12 0 G
```

Fig. 3. Example of a MaxList file

The source code from both type of microcontrollers is inaccessible and is not provided when the Switching Matrix is purchased. Since the Switching Matrix is a proprietary hardware, the software is exclusive to that solution and because it is not accessible, nor are there any publications explaining it, it is not feasible to use another kind of matrix (commercial, etc.) to control the remote experiments platform with it. However, the limitations with the Switching Matrix of the VISIR remote laboratory software also occur with the Equipment Server. Beyond that it is not easy to understand how this server works, and that it has never been documented, the code is quite extensive and has many relational links between the different blocks. So, it is impossible to maintain the Equipment Server, it is not easy to compare the different revisions made over the years, and it can take a long time to update the code, if necessary.

Another software limitation is because LabVIEW code does not compile into a binary program, so is not fast and the Switching Matrix performance is reduced.

From the repeated use of the VISIR remote laboratory, other technical limitations in the Switching Matrix are identified, such as:

- The connection cables, which, due to the arrangement of the bus connectors connecting the nodes to the components and shortcut wires, may experience a break in electrical continuity, faulty contact, or short-circuit.
- The component Boards sockets, where components and all shortcut wires must be physically placed, have holes too small to accommodate certain elements, such as diodes.
- The electromechanical relays that often malfunction, and since these failures are usually random, they are almost always only noticeable when students are conducting the experiments.
- The firmware drivers that have not been updated for a long time, causing compatibility issues when changing the operating system on the computer which contains the servers.

B. *Educational or pedagogical limitations*

The approach used in the design of the Switching Matrix results in redundancy of components and shortcut wires, which necessitates the use of more Component Boards on the platform to implement the desired circuit. Economically, this is unsustainable, so it becomes necessary to organize laboratory activities with the available elements, thereby reducing the diversity of pedagogical content that can be addressed simultaneously. Thus, this hardware limitation impacts the complexity of allowed circuit topologies, restricting their use to courses that use simpler circuits [7]. It is worth noting that this low complexity of available circuits for students is also due to the scarcity of nodes on the Component Boards [12].

Since the ammeter must be connected in series with the other components of the circuit, in the Switching Matrix, it must be placed in a short circuit between two different nodes. Therefore, it is essential to always indicate to students where to locate this measuring instrument, which means that pedagogically, they do not understand that it is possible to position it elsewhere in the circuit.

Another limitation that also prevents the execution of some more complex experiments is the fact that the current intensity that can cross the electromechanical relays placed on the Component Boards of the Switching Matrix is constructively limited to 500 mA.

Thus, given these limitations of the Switching Matrix, for teachers and specialized technical personnel, creating, preparing, and designing circuits requires alternative approaches to those normally adopted to perform the same task in conventional laboratories.

C. *Operational limitations*

Regarding operational limitations, it is observed that there is some difficulty in maintaining, updating, and/or accessing the components and shortcut wires installed on the Component Boards because, as they are stacked, it is necessary to remove each one individually to perform these tasks. Additionally, it is not easy to know which of the electromechanical relays is faulty without having to remove them all from the Switching Matrix, that is, without stopping the VISIR remote laboratory, increasing the maintenance time required to locate the faulty device. This leads to another limitation, namely, the absence of a message informing that the Switching Matrix is under maintenance, which causes students not to understand why they cannot access the platform.

The absence of a protective enclosure for the Switching Matrix is also notable, leading to safety, reliability, and stability issues, as it is not equipped with, or associated with, a specific dedicated mounting base.

The dependency on internet network connectivity can also be a sensitive point, as failures or latency issues can impact the student experience. Therefore, it is essential to implement robust monitoring and maintenance measures to ensure reliable operation of the Switching Matrix in the VISIR remote laboratory.

D. Economical limitations

Being the VISIR remote laboratory a real-time platform, it is understood that its development and maintenance are costly. Therefore, one of the major limitations of the Switching Matrix is the cost at the time of its acquisition. In addition to this high initial investment, since the deployment of this platform relies directly on the use of hardware (including the Switching Matrix) and specific software for which it was designed, this results in an excessive price for each laboratorial session [13]. As LabVIEW distribution is not a free software, it is also appropriate to include it in these initial costs without forgetting that the license needs to be renewed every year.

To function correctly, it is necessary to place components on the Component Boards of the Switching Matrix, which means devices that have a cost that can vary. This expense may be relatively low, as in the case of electrical resistors, or higher, such as with op-amps, but whatever the type of component, the amount spent will always be less than in a conventional laboratory.

Since the Switching Matrix is a proprietary solution, one of its limitations is its low likelihood of being reused in a system other than the VISIR remote laboratory. Therefore, the financial investment made can only be recovered through the intensive use of the platform.

The complexity of the Switching Matrix can make its configuration and maintenance challenging, requiring specialized technical knowledge for diagnosis and problem solving, as well as for circuit creation, design, and debugging. As it involves a complex activity that requires knowledge of electricity, electronics, and computer science, as well as the ability to integrate circuits with software and hardware, specialized technical personnel are required, which entails excessive costs. However, almost all installed platforms are developed, maintained, and managed by graduate students, professors, and researchers because organizations do not have the financial resources to have a permanent team.

IV. Conclusions

The VISIR remote laboratory, despite being a platform for practical experimentation at a distance in the field of analog electronics and electricity, which is used very frequently, faces its own challenges as a whole, but also in very specific parts, such as the Switching Matrix.

By reviewing all the relevant information available, along with feedback from intensive user and owner experiences, in this work the main limitations currently existing in the Switching Matrix have been identified, understanding, among other things, that these are related to hardware and software, but also educational or pedagogical, operational, and economic aspects. It is also understood that, due to these limitations, there is a reduction in preparation flexibility of laboratory activities, as well as low reuse of platform components, almost non-existent interoperability unless with the devices themselves, and high hardware costs of the Switching Matrix.

Because a lot of these limitations are considered threats and upcoming attempt to dissemination, it is essential, if one intends to keep this platform operational for several more decades, for example, to capitalize on its acquisition cost, to promptly proceed with significant improvements. These ones, that can, with greater or lesser easiness, overcome all the limitations identified without forgetting that there is an interconnection between all the constituting parts of the VISIR remote laboratory. That is, technical improvements are needed and essential to increase flexibility and performance, while decreasing third-party dependence such as Switching Matrix and LabVIEW cases replacing them by other technologies.

Despite the obstacles related above, the VISIR remote laboratory represents a milestone in the evolution of science and engineering education because it democratizes access to practical education and promotes global collaboration among educational institutions.

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