

## Article

# Cloud-Based, Expandable—Reconfigurable Remote Laboratory for Electronic Engineering Experiments

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**Abstract:** This article describes the design and development of the NI myRIO device-based remote laboratory. The cloud-based, expandable, and reconfigurable remote laboratory is intended to give students access to an online web-based user interface to perform experiments. Multiple myRIO devices are programmed to host several experiments each. A finite state machine is used to select specific experiments, while a single state can contain several. The laboratory web virtual instruments interfaces are hosted on the SystemLink cloud and SystemLink server. A user-friendly interface has been designed to help students to understand important electronic concepts. Virtual and real experiments were fused to give students a wide range of experiments they can access online. The instructor can check outputs of an experiment being executed on the device. Achieving connection between myRIO and SystemLink through global variables and SystemLink ensured that the low-cost device was utilized, and this is suitable for third-world countries' universities that cannot afford expensive equipment. Students can perform the experiments which have some resemblance to physical execution. The system is expandable in that the number of myRIO devices or number of experiments can be increased to suit changing requirements. The reconfigurability of the system is such that the finite state machine-based coding technique permits only one experiment to be selected, configure the system, and run while other experiments are idle.

**Keywords:** remote learning; remote laboratory; reconfigurable; SystemLink; cloud; myRIO



**Citation:** Chamunorwa, T.; Modran, H.A.; Ursuțiu, D.; Samoilă, C.; Hedeșiu, H. Cloud-Based, Expandable—Reconfigurable Remote Laboratory for Electronic Engineering Experiments. *Electronics* **2022**, *11*, 3292. <https://doi.org/10.3390/electronics11203292>

Academic Editors: Juan M. Corchado, Byung-Gyu Kim, Carlos A. Iglesias, In Lee, Fuji Ren and Rashid Mehmood

Received: 14 September 2022

Accepted: 11 October 2022

Published: 12 October 2022

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## 1. Introduction

In a globalized world, life has become heavily dependent on the utilization of interconnected devices [1]. An ever-increasing number of people rely on smart devices for social, business, and educational purposes. The over-dependence of today's people on technology has led to the demand for educational institutions to be involved in continual research and development (R&D). To obtain practical proficiency in engineering training, experimentation on real equipment in labs is essential. With the rising need for remote exploration and monitoring services, a case of e-learning or computer-based remote learning (CBRL) becomes more imperative [2]. CBRL has become increasingly essential to electronic engineering education, primarily in laboratory courses, and the COVID-19 pandemic has made the computer an indispensable tool for learning. In electronic engineering laboratory courses, learning includes the usage of integrated development environment (IDE) software and hardware development boards. When the educational embedded development boards are configurable and internet-connected, laboratory services will be versatile and remotely

accessible. The main goal of this article is to devise different methods and systems for computer-based education in digital electronics, particularly for remote laboratories.

One of the major aspects of learning engineering concepts is hands-on practice. The need to shift laboratory experiments to remote and virtual platforms has been on the radar for a long time. The sudden onset of the COVID-19 pandemic meant that all learning institutions had to completely shift to online learning overnight. The need to conduct hands-on laboratories—a mainstay of engineering programs—remotely seems a practically unassailable challenge [1]. There has been considerable research conducted on remote and virtual engineering [3]. The study, teaching, and learning of the embedded system which forms the heart of these networked devices has never been more important. This study seeks to proffer an adaptable embedded platform. Teaching and learning have undergone a tremendous transformation in recent years. The improvement of training methodologies has been a continual process in academics and industry, in line with technological advancements.

The technological environment usually changes very quickly. A lot of previously popular technologies are being phased out. This phenomenon cannot be attributed to human or natural disasters but is instead a result of innovation and advancement of state-of-the-art technologies [4]. Thus, the never-ending research into teaching and learning is a necessity so that education and training do not lag. This study has been necessitated partly by the need to address challenges and shortcomings raised by former electronics engineering students through a survey; these concerns, in general, apply to many engineering faculties. The study is also in line with the 2030 Agenda for Sustainable Development, which presents the primary innovation challenge for emerging countries to advance their capability to learn, take on, and spread current skills and technologies to encourage continual and comprehensive development. The goal is to improve innovation and step up concept-to-deployment in designing in line with leading universities worldwide. According to [5], universities face the challenge of aligning their primary missions with the quick advent of technological innovations and other yet-to-be-created technologies.

The current study seeks to explore ways to enhance the offline and online teaching and learning of embedded systems laboratories and STEAM (Science, Technology, Engineering, Arts, and Mathematics) technology. It also seeks to devise new rules in the didactic process through the intended learning environment, which is essential as the COVID-19 pandemic has proven that “face-to-face” lessons are not enough. This article seeks to create a new framework for the virtual and remote learning environment and prepare young people for engineering careers.

## 2. Related Work

Humanity has seen disruption of its lifestyle by the breakout of the COVID-19 pandemic. Instructors in universities had to perform their laboratories and classes online [6]. Many online system laboratories were quickly established to mitigate learning disruption, but conducting laboratories online was not without its difficulties. In African Universities, online laboratories have been recognized to facilitate learning during and after the COVID-19 pandemic period. A mixture of challenges faces the setup of such labs which are nonexistent in Southern Africa, except in South Africa. The main challenge is the cost, and hence, pooling of resources or joining existing platforms has been encouraged [7]. The goal of instructors has been to create tools for conducting laboratories as established by [8–19].

A software platform was adopted to connect a real lab to students online [9]. MATLAB, LabVIEW, and Arduino were used to allow students to remotely experiment with a DC motor circuit for vibrations and transient analysis. The setup is limited to one type of experiment, and it has no cloud connectivity. This study proposes a platform that covers multiple concepts in electronics by combining digital, analog, control, and IoT with access to the cloud. Other universities resorted to giving student take-home kits [8] for introductory electrical laboratory courses. The kits consisted of all components necessary for learning basic circuits, including capacitors, resistors, LEDs, Arduino Uno, and multimeters, among others. The challenge was the lack of debugging assistance available to students.

A remote system in [10] was established which involved remote access to an FPGA platform in the lab. The student could develop a program on their computer and only access the board to run the code through a cloud platform. The setup could not fulfill the hands-on type of simulation. This study proposes a hybrid of experiments with simulations and hardware interactions. Altalbe [11] proposes a system to monitor the sensor data, and it allows the learner to work remotely using a mobile Android device. The physical lab consists of a mechanically configurable testing rig, while this study proposes that the use of a software-configurable embedded platform will increase the range of experiments that can be performed by students.

A remote debugging system is presented in [14], and it can be improved by developing a dashboard that covers all experiments. Vince et al. [15] present a simulator for power electronics control, an expansion on concepts covered, and online access is suggested to enhance the system. Another study [17] presents a system that connects a microcontroller to a remote C# application, and a proposal is made to include an integrated hardware platform that will expand the scope of laboratory sessions. A Tinkercad platform-based system is presented in [19], and a dedicated PCB with processing controllers is proposed in addition to a prototyping platform to expand the laboratory scope. An IoT-based laboratory is described in [20]: the system creates a remote connection between different devices, and the authors suggest including configurable hardware to expand on several experiments and flexibility.

The authors of [21] aim to identify and quantify the main factors affecting mechanical engineering student performance in the context of the COVID-19 pandemic, to build a generalized linear autoregressive model for predicting student grades in online learning situations in hybrid environments. The refined version of the model they developed predicts student grades with a margin  $\pm 1$  with a success rate of more than 63.70%.

In another study [22], the grade prediction in a first-semester mechanical engineering CAD module is explored. The authors developed a hybrid model with 35 features that are strongly correlated with the students' academic performance. An artificial neural network (ANN) with three layers was selected for the model, and it achieved a 100% success rate.

Z. Kanetaki et al. [23] presented a case study concerning the evaluation of the online task assignment of students, using Microsoft Teams. Their aim was to determine whether it can be used to avoid potential problems which can occur during the teaching process. This study revealed the special features of fully online teaching specifically, and its role in improvement of assessment using digital tools.

### 3. Materials and Methods

#### 3.1. Designing and Developing the System

The developed CVTC remote laboratory is a platform to access experiments hosted on remote NI myRIO hardware. The experiments are accessed through the NI Web VI hosted on a SystemLink server. The delayed test led to a decision to host the lab web VIs on the SystemLink server since it offers better performance than the cloud platform. The link to access the lab is <https://cvtc.unitbv.ro> (accessed on 20 September 2022). The student can select an experiment to conduct using a selector tab on the interface. Each lab has its specific learning objectives.

This section describes in detail the materials and methods used for this experiment; Figure 1 illustrates the 4 subsections.

Figure 2 illustrates the laboratory platform structure. It contains several interconnected myRIO devices that can be accessed remotely. The myRIO devices are connected to the instructor PC through the USB cable or Wi-Fi protocol (Figure 3). In the LabVIEW project hierarchy, the deployed FSM codes are under the myRIO devices, and the intermediary code is above the myRIO device (Figure 4).

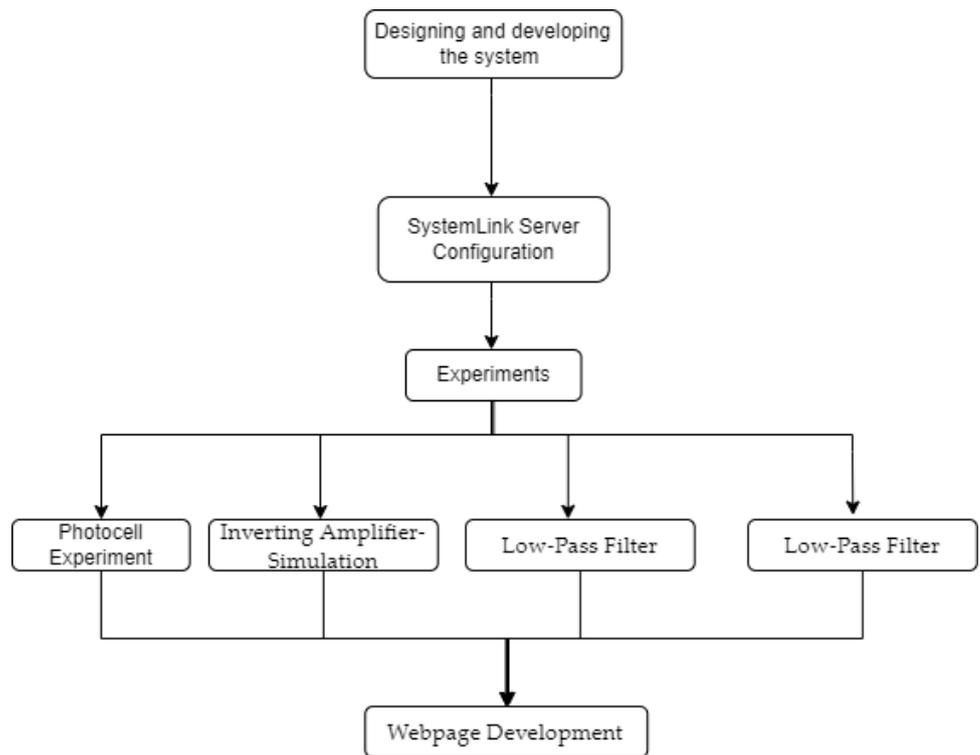


Figure 1. Subsections of Section 3.

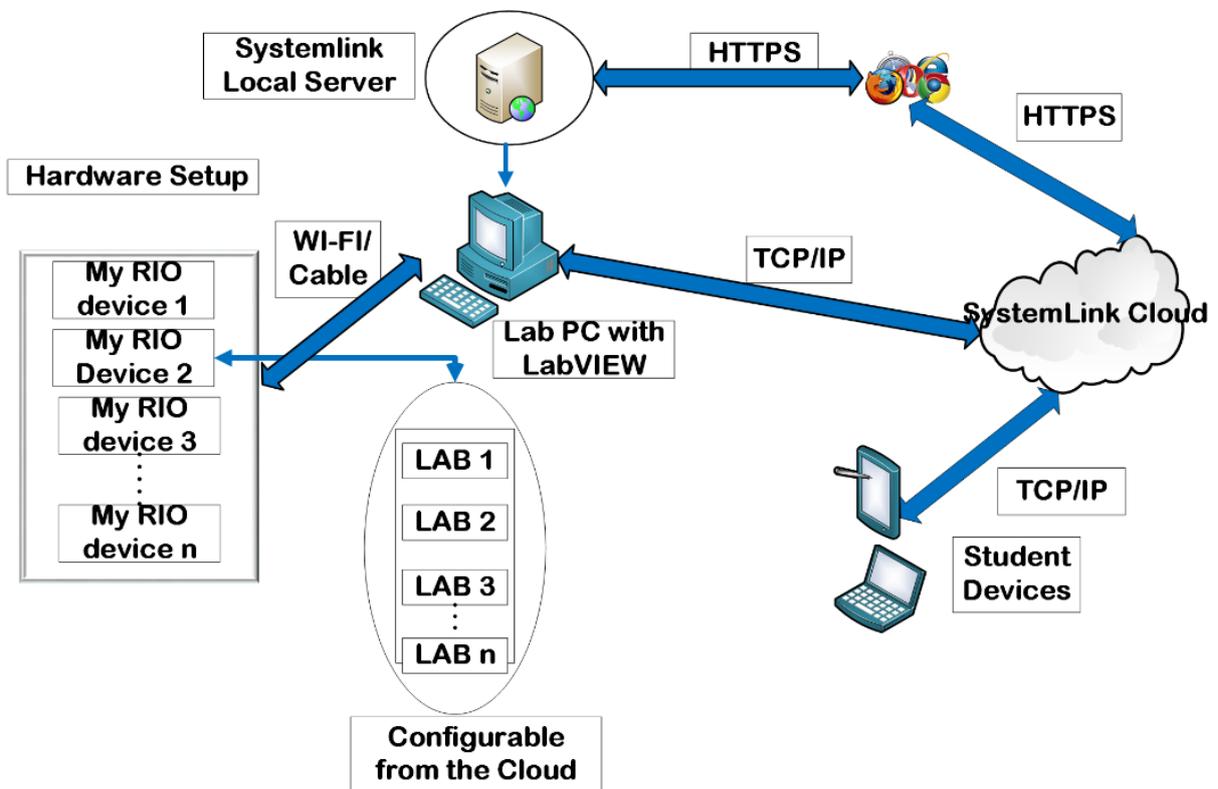


Figure 2. Laboratory platform structure.

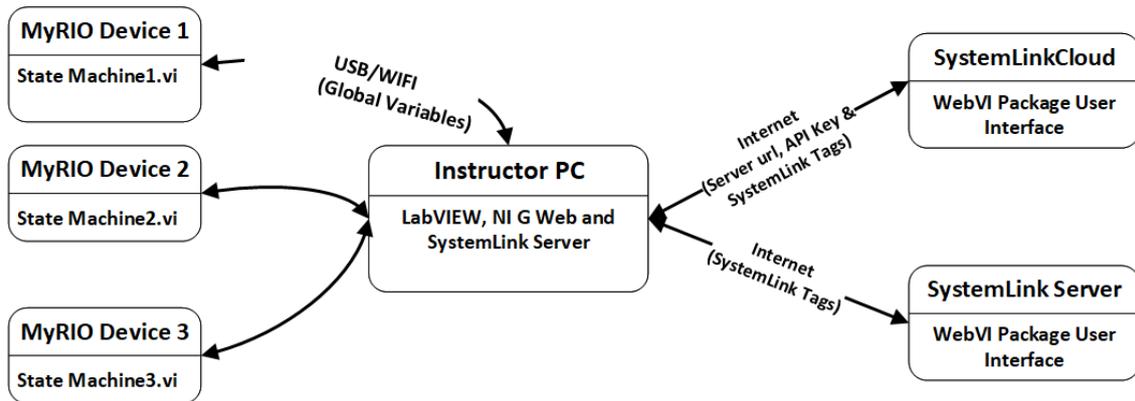


Figure 3. System interconnectivity.

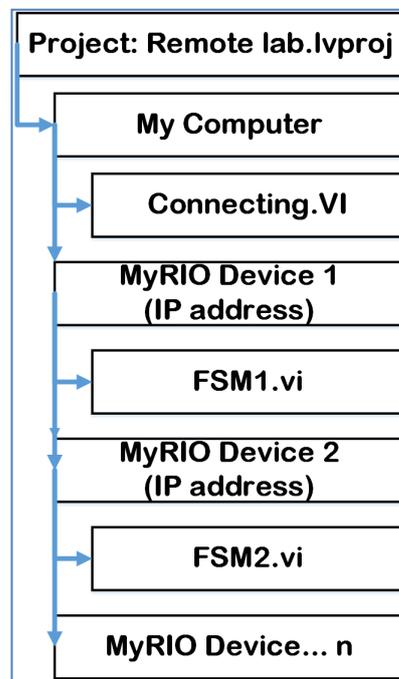


Figure 4. LabVIEW Project Hierarchy.

Figure 3 is a representation of the system connection overview. Each rounded rectangle represents a hardware or server platform. For instance, MyRIO Device 1 contains the state, and the instructor PC has the indicated software installed. The transition arrows show the flow of information from one platform to another. For example, the movement of data from the PC to the Web VI hosted in the SystemLink cloud is enabled by configuring the server URL, API key, and associated tags.

Each myRIO device contains a LabVIEW-based finite state machine (FSM) code deployed inside and can accommodate multiple experiments. The interfaces are observable on a single tab in a web interface. The FSM technique enables the selection of specific experiments to run while others are on hold, making the platform configurable. Experiment codes from the same state execute independently of each other. Figure 5 illustrates the code for one of the states (Logic Gates).

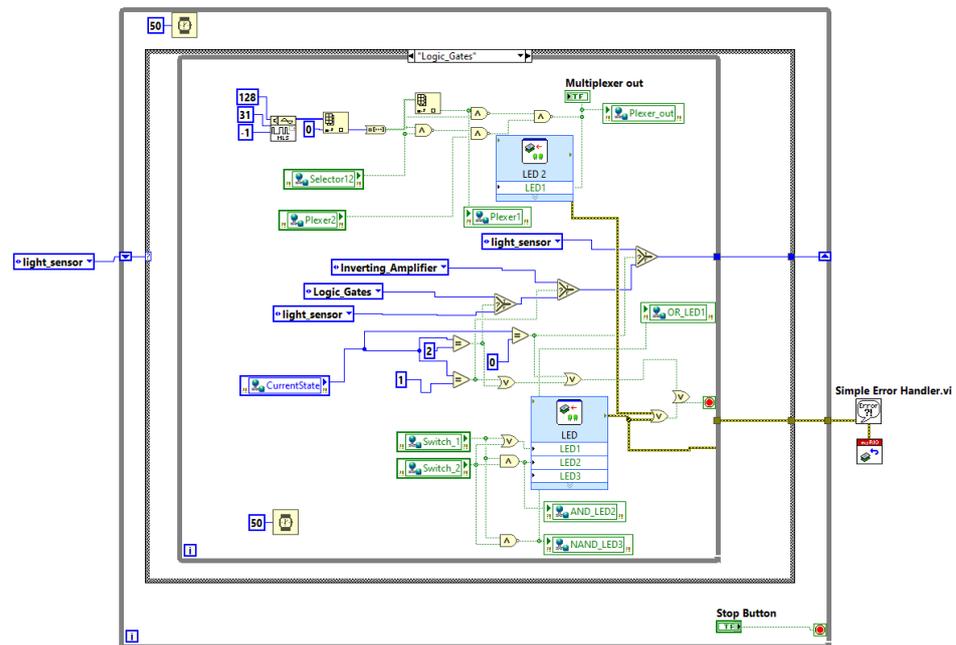


Figure 5. LabVIEW Code for Logic Gates state.

The finite state machine LabVIEW code from different devices execute independently from one another (Figure 6).

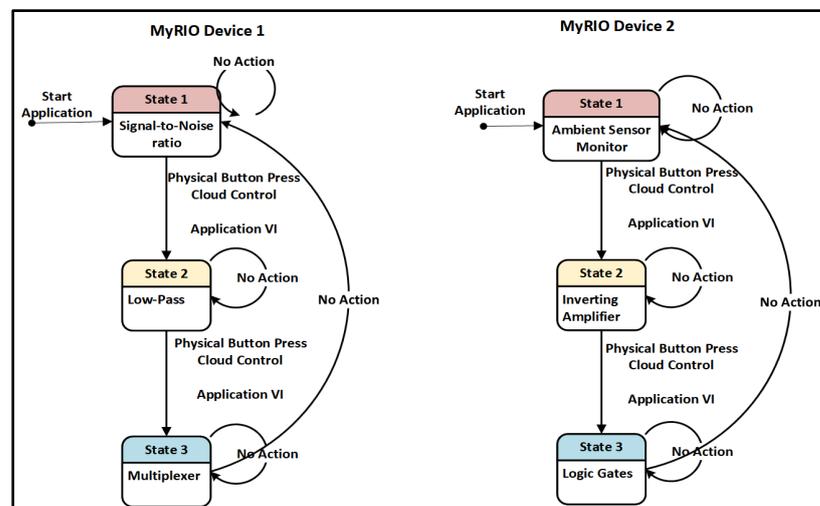


Figure 6. State machines running on different MyRIO devices.

The lab setup is such that myRIO devices are connected to the computer either by cable or Wi-Fi. Each myRIO device contains a finite state machine-based VI deployed in it. An FSM can contain any number of states. There are also VIs which execute in the PC and communicate with VIs in the myRIO devices and SystemLink cloud tags. The FSM codes deployed inside myRIO devices transmit data to and from the code running in the PC through global variables. The code running in the PC functions as a data transfer intermediary between the codes deployed in the myRIO device and the web user interface. The intermediary LabVIEW code executing in the PC receives data through the global variables from the myRIO device and transfers them to the web interface through SystemLink tags. Data transfer from LabVIEW to SystemLink cloud requires an application programming interface (API) key and cloud server URL specified on the open configuration VI in LabVIEW. SystemLink tags are created in SystemLink cloud and SystemLink server,

and each tag has a unique name and a data type. The tag name and data type are matched and specified on the tag VI in LabVIEW (Figure 7).

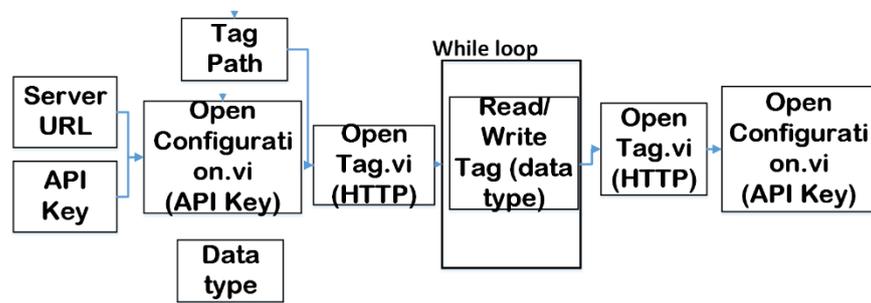


Figure 7. SystemLink Cloud API Connection.

The data from LabVIEW are sent to a Web VI hosted on SystemLink server or SystemLink cloud. The Web VI is created in NI G Web development software which employs the graphical language used in LabVIEW. The Web VI receives data from tags using the same configuration as LabVIEW.

The front panel of the Web VI is customized to suit the required user interface corresponding to the selected experiments. The steps to create the Web VIs are as follows:

1. Design the G Web development software block diagram to receive indicator data from SystemLink tags.
2. Use the G Web block diagram to send control data to SystemLink tags.
3. Configure appropriate indicators for received data.
4. Design a tab-based front panel to enable a choice of labs in synchronization with the finite state machine configured in the myRIO device.
5. Evaluate the design on localhost.
6. Build the Web VI into a nipkg file.
7. Upload the file on SystemLink server or cloud platform.

### 3.2. SystemLink Server Configurations

The NI Web Server Configuration wizard was used to configure the SystemLink server. The configured aspects are as shown in Figure 8.

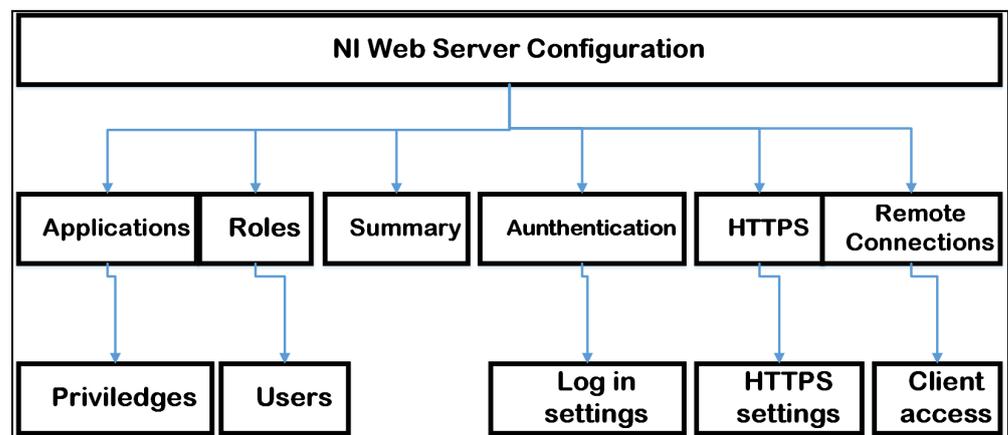


Figure 8. Server Configuration Wizard Aspects.

The configured aspects included users’ roles, authentication, and connections.

### 3.3. Experiments

This section describes some of the experiments that were created for the laboratory platform.

There are objectives that are common to all experiments. This task involves writing a G web code which can send and receive data from the cloud using tags, server URL, an appropriate data type, and an API key for security. After performing the experiments, the students should be able to:

- Appreciate the role of SystemLink in data storage and transfer.
- Understand how to read and write to SystemLink tags.
- Understand the relationship between a tag and its path.
- Appreciate the relationship between tags, indicators, and controls.
- Built VIs to interact with data from SystemLink server.
- Understand the connection of hardware circuits to the cloud platform (Figure 1) and build projects based on this principle.

#### 3.3.1. Photocell Experiment

A physical circuit for the Figure 9 setup exists in the remote lab. The setup consists of a photocell connected in a voltage divider circuit which responds to varying light intensity. The source of the light is an LED whose intensity is varied using the PWM principle. The PWM variation is achieved through the PWM express VI in myRIO toolkit in LabVIEW. As the incident light changes in intensity, so does the output voltage connected to a myRIO analog input. The PWM variation is emulated on the web user interface. The output voltage is then transferred to the web interface through global variables and tags and is visualized graphically. The laboratory platform can have several of these circuits accessible independently on one or several myRIO boards (Figure 10).

The steps of the experiment are shown on the user interface. After performing this experiment, the learner will be able to:

- Understand the characteristics of a photocell (the relationship between light illumination and resultant resistance).
- Appreciate the Pulse Width Modulation Concept.
- Understand the working principle of a voltage divider rule.
- Build a simple alert system to indicate light thresholds limits.

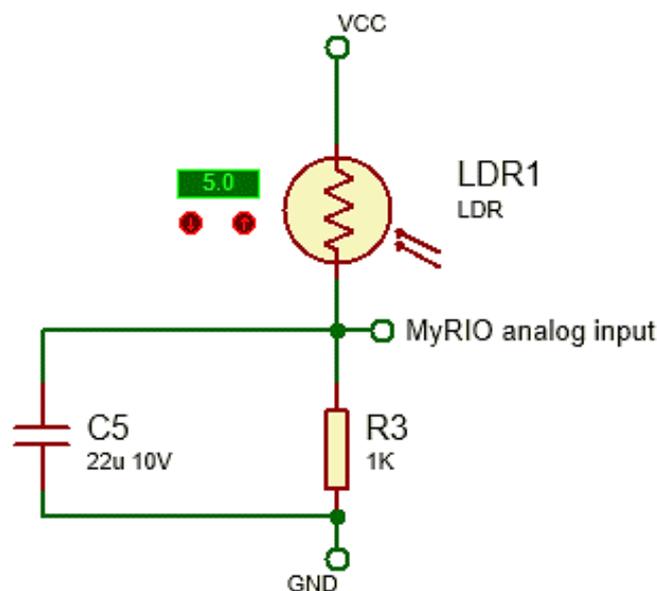


Figure 9. Photocell circuit setup.

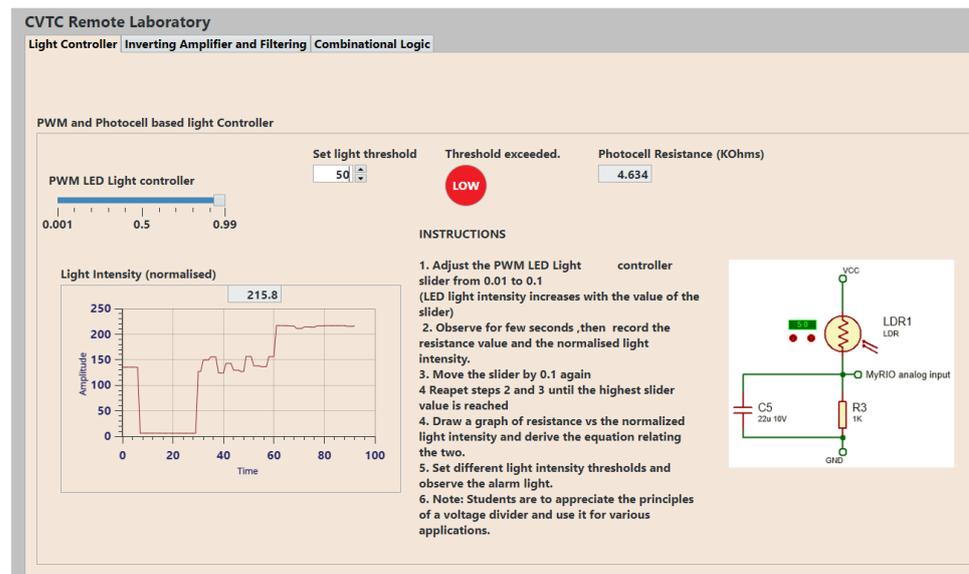


Figure 10. Photocell and Thermistor laboratory interface.

### 3.3.2. Inverting Amplifier Simulation

The experiment (Figure 11) illustrates the working principle of an inverting amplifier. The setup consists of an inverting operational amplifier input voltage, input resistance, output resistance, and an output voltage. The inverting amplifier is simulated in LabVIEW, and the functionality is emulated on the web user interface. A constant input voltage is generated, and input resistance is kept constant as output resistance is varied, thereby changing the output gain. LabVIEW can be configured to emulate this setup multiple times, and students can access the several copies independently.

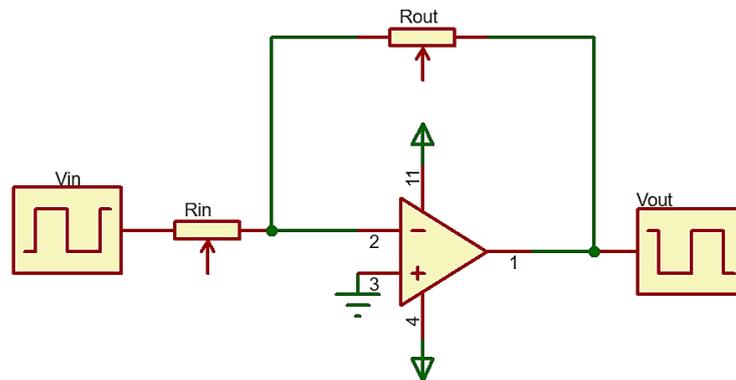


Figure 11. Inverting Amplifier Schematic.

By the end of this experiment, the student will be able to:

- Understand the characteristics of an inverting amplifier.
- Appreciate the effect of resistor ratio in the gain of an amplifier.
- Build a simple alert system to indicate voltage thresholds limits.
- Differentiate between inverting and non-inverting amplifiers.

From Figure 12, the gain of an inverting amplifier is expressed as:

$$Gain = \frac{R_{out}}{R_{in}}$$

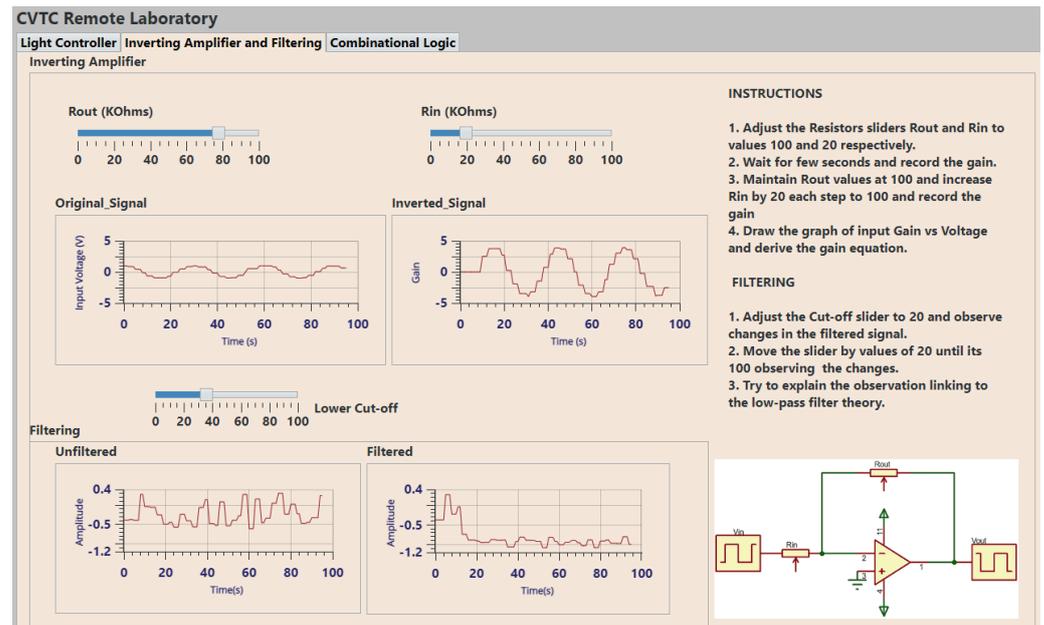


Figure 12. Inverting Amplifier and Signal filtering lab interface.

Steps of the experiment:

1. Open the Experiment User interface.
2. Choose the Lab 3 and 4 tab options (Figure 12).
3. Adjust the resistor 1 and resistor 2 sliders to 100, wait for a few seconds, and then record the gain steady value (i.e., Inverted Signal).
4. Maintain resistor 2 at a value of 100 and change resistor 1 by a value of 20.
5. Repeat steps (3), (4), and (5) down to the value of 20.
6. Draw the graph of resistor 1 values versus gain.
7. Postulate what a non-inverting amplifier graph would look like.

### 3.3.3. Low-Pass Filter

This experiment illustrates the working principle of a generic low-pass filter. By the end of this experiment, the student will be able to:

- Understand the characteristics of a low-pass filter.
- Appreciate the effect of a cutoff frequency in low-pass filters.
- Differentiate between low-pass and high-pass filters.

Steps of the experiment:

1. Open the Experiment User interface.
2. Choose the Lab 3 and 4 tab options (Figure 12).
3. Adjust the cutoff frequency from a value of 0 in steps of 10 up to 100.
4. Wait for a few seconds and observe the results.
5. Postulate how a high-pass filter would behave.

### 3.3.4. Basic Logic Gates and Multiplexer

The experiment illustrates the working principle of basic logic gates and a 2-to-1 multiplexer. The logic gates setup consists of three logic gates, an OR gate, AND gate, and NAND gate. The logic gates are connected to three outputs and to two inputs which are toggled from 00 to 11. Each logic gate output is observed on the web interface and on the myRIO device LED in the lab. The multiplexer consists of the 2 inputs and selector input which are connected to logic gates network, forming a 2-to-1 multiplexer. The output reflects the status of each input depending on the selector state (0 or 1). The output shows a

blinking LED or the state of the other input (ON or OFF). These setups can be replicated to enable independent access by different students.

By the end of this experiment, the student will be able to:

- Understand the characteristics of an AND, OR, and NAND gates and a 2-to-1 multiplexer (Figures 13 and 14).
- Understand truth tables for the logic gates.
- Appreciate that the changes are also mirrored in hardware.

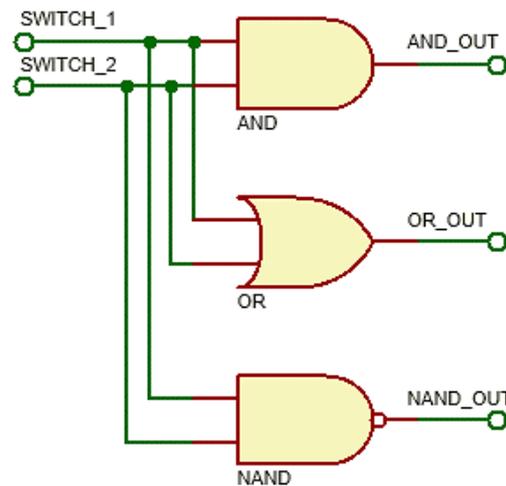


Figure 13. Basic logic gates circuit configuration.

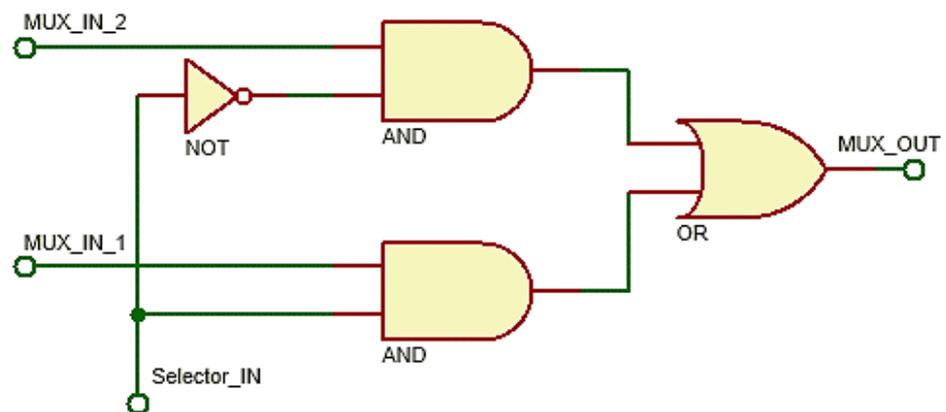


Figure 14. Multiplexer circuit.

Steps of the experiment:

1. Open the Experiment User interface.
2. Choose Lab 5 and 6 tab option (Figure 15).
3. Toggle Switch\_1 and Switch\_2 using the pattern shown in Table 1 and fill in the results in the table.
4. Record whether the logic gates indicators are red (on) or green (off).
5. Compare results with truth tables in textbooks.
6. Toggle Selector\_IN and MUX\_IN\_2 using the pattern shown in Table 2 and fill in the results.
7. Record whether the MUX\_OUT indicator is red (on) or green (off).
8. Compare results with truth tables in textbooks.

**Table 1.** The truth table for basic logic gates.

Switch_1	Switch_2	AND	OR	NAND
Off	Off			
Off	On			
On	Off			
On	On			

**Table 2.** Truth table for 2-to-1 Multiplexer.

Selector_IN	MUX_IN_2	MUX_IN_1	MUX_OUT
Off	Off	X	
Off	On	X	
On	X	Off	
On	X	On	

The screenshot displays the CVTC Remote Laboratory interface for 'Combinational Logic'. It features several simulation panels:

- 2-to-1 Multiplexer:** Includes a 'Blinking Input' (On), 'MUX\_IN' (Off), and 'Selector\_IN' (On). The 'MUX\_OUT' is shown as a blue circle.
- Basic Logic gates:** Shows 'Input 1' (On), 'Input 2' (On), and outputs for 'OR\_LED' (On), 'NAND\_LED' (Off), and 'AND\_LED' (On).
- Binary to Decimal conversion:** Shows a binary input of '0011' resulting in a decimal output of '12'.
- 2 to 4 decoder:** Shows inputs 'A' (Off) and 'B' (On), with outputs 'Q0 = A'B'', 'Q1 = A'B', 'Q2 = AB'', and 'Q3 = AB'.

Below the panels are two circuit diagrams: one for the basic logic gates (AND, OR, NAND) and one for the 2-to-1 multiplexer implementation using logic gates.

**INSTRUCTIONS**  
 Basic Logic gates ( OR, NAND, AND )  
 1. Toggle Input 1 and Input 2 through this pattern,  
 OFF OFF  
 OFF ON  
 ON OFF  
 ON ON  
 Observe and record the output in a truth table for the 3 gates.  
 Multiplexer  
 1. Toggle MUX\_IN and Selector\_IN through this pattern,  
 OFF OFF  
 OFF ON  
 ON OFF  
 ON ON  
 Observe and record the output in a truth for the Multiplexer

**Figure 15.** Basic Logic gates and Multiplexer.

### 3.4. Web Page Development

This section outlines the development of a website hosting various labs. The labs were selected to show the proof of concept of the remote laboratory platform ecosystem. The website is found at: <https://sites.google.com/view/cvtc-lab/home> (accessed on 20 September 2022). The home page is shown in Figure 16. The page gives options to go to different labs. The Website hosts both myRIO-based remote experiments and Multisim-based virtual experiments.



**Figure 16.** The Laboratory Home Webpage.

#### 4. Results and Discussions

This section provides the conclusion to this article and suggests future study opportunities and recommendations. The study was undertaken by the Center for Valorization and Transfer of Competence (CVTC) at the Transylvania University of Brasov, which enjoys a fruitful partnership with Cypress-Infineon and NI Romania, fostered by the current center president Doru Ursuțiu. The student board and the teacher’s platform page simulation have been tailor developed from various reference designs and hardware and software resources from those partners. The main advantage was the permission to develop from the offered software and hardware resources platforms. Student feedback is an ongoing process and is being conducted on Google forms link: <https://forms.gle/usQLK4GuhNLT47aJ9> (accessed on 3 October 2022).

The current study achieved the following innovative and original ideas:

1. Development of an instructor platform
  - Three myRIO devices (with the possibility of adding more devices if expansion is required).
  - Three labs per device (can also be extended to suit requirements).
  - The transfer of data from State Machine VI running in the MyRIO device to the VI running in the computer enabled by global variables.
  - Splitting the VIs to have the connecting VI run under the computer and the state machine VIs run under MyRIO devices—an original idea which was devised since MyRIO (with a 256 MB memory limitation) cannot manage a SystemLink installation to work as a direct client to the server.
  - Hosted on both SystemLink server and cloud platform.
2. Webpage development
  - MyRIO remote labs hosted on physical devices.
  - Accessible on NI G Web VIs.
  - Multisim live simulation laboratories.
  - Theory and instructions.

LabVIEW is a great tool for engineering learners as it offers an intuitive graphical programming environment. The graphic methodology to programming bodes well with engineering learners who are used to demonstrating solutions utilizing process diagrams. The software also proffers a straightforward way of FPGA designing by abstracting many aspects and allowing students to concentrate on their algorithms. The SystemLink environment presents an appropriate platform for performing laboratories through the internet and applying SystemLink cloud services and dashboard mobile application.

The blending of LabVIEW, SystemLink server, SystemLink cloud, and NI Web Vis on this laboratory platform is an innovative ecosystem for IoT designs and remote laboratories. The ecosystem is suitable for learners with inadequate access to costly laboratory equipment, and it is a superb platform for remote laboratories. NI real-time hardware devices with

more than 512 MB RAM can connect with LabVIEW and SystemLink cloud platform to structure remote educational laboratories and industrial process control.

## 5. Conclusions

The designed laboratory platform was based on the NI myRIO devices to deliver a valuable experimental online platform for electronic engineering lab classes. The platform is a flexible and adaptable design since different sensors can be substituted with each other through the Pmod connectors. The integrated sensors supplied by the Diligent company offer straightforward connections throughout prototyping. The myRIO device expansion port (MXP) connector has interior protection; learners only focus on top-level circuit design. The existence of the FPGA chip and ARM processor in myRIO makes it feasible to implement different functionalities with variable intricacy.

The methodology expressed in this study could be considered a proof of concept, inspiring related projects that may aid a broad range of engineering and technology learners all over the world. The easy-to-program software and hardware, combined with the easy-to-connect solutions, are requirements for a post-COVID-19 education world, where the necessity for information transfer and assimilation is facing the trials of social distancing. The study contributes knowledge on learning methods in the post-COVID-19 era and demonstrates how to conduct STEAM classes using a combined platform for hardware and simulated labs. The development of an expandable, inexpensive, and configurable remote platform challenges the way professors, especially in the sub-Saharan region, conduct experiments. The complaints about inadequate resources could be solved as universities can come together to develop powerful combined platforms for their faculties. Furthermore, an LDR camera will be added so that the students can observe the physical devices live.

**Author Contributions:** Conceptualization, T.C., H.A.M. and D.U.; methodology, C.S. and H.H.; software, T.C. and H.A.M.; validation, D.U., C.S. and H.H.; formal analysis, T.C. and H.A.M.; investigation, T.C.; resources, T.C., H.A.M. and D.U.; data curation, H.A.M.; writing—original draft preparation, T.C. and H.A.M.; writing—review and editing, D.U. and C.S.; visualization, D.U., C.S. and H.H.; supervision, D.U.; project administration, C.S.; funding acquisition, D.U. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** We would like to express our deep appreciation to the National Instruments company for providing us with LabVIEW and SystemLink licenses, thus facilitating our experiments.

**Conflicts of Interest:** The authors declare no conflict of interest.

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