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New Methods and Systems for Computer-based Learning in Digital Electronics Education

SUMMARY

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Contents

ABSTRACT

During the author's ten years of teaching practical-oriented engineering courses at three technological universities in Zimbabwe, several challenges were experienced while conducting practical experiments. The challenges necessitated the study and the development of a novel framework for teaching and learning electronic engineering concepts in laboratories using both offline and online resources. The framework is divided into two basic concepts: developing a remote laboratory learning system using expandable hardware and configurable software systems and creating software-configurable hardware using a PSoC 6-based multi-peripheral board. A PSoC 6 CYBLE Creator module, which is reprogrammable in terms of both software and hardware, was used to create the student board. The PSoC module was chosen as an alternative to FPGA-based chips since it is less expensive. Because PSoC design uses the schematic capture programming style, it offers a more gradual learning curve than FPGAs. The student board includes stack connectors compatible with Arduino that can connect a variety of shields as well as Pmod (Peripheral Module Interface) connectors for attaching a variety of peripheral modules. The online platform for teachers is analogous to an IoT ecosystem. It has hardware nodes linked to a cloud computing platform. The myRIO student-embedded device was selected as the hardware platform. The hardware was then connected to the SystemLink server and cloud platforms. For the online remote laboratory platform that contains multiple experiments in a single myRIO device, a method for reconfiguring the device from a cloud platform to select specific experiments was developed. An original method was devised to transport data between the myRIO device and the cloud. Using a two-stage mechanism, data was transferred from the myRIO device to the computer using global variables, and from the computer to the cloud using SystemLink tags. The two-stage connection was utilized because it eliminated the installation of SystemLink client software in the myRIO device, which would enable it to be a standalone client but would certainly lead to system failure because of myRIO memory constraints. This communication also conserves memory, which is used to store and run experiments. WebVI-based interfaces were designed using the G Web development tool, and the SystemLink server and cloud were used to host them.

1 INTRODUCTION

During the author's ten years of teaching practical-oriented engineering courses at three technological universities in Zimbabwe, several challenges were experienced while conducting practical experiments. The challenges necessitated the study and the development of a novel framework for teaching and learning electronic engineering concepts in laboratories using both offline and online resources. An opportunity to study at the Transylvania University of Brasov in Romania under the Centre for Valorization and Transfer of Competence (CVTC) made it possible to realize a novel framework for conducting laboratories. The challenges facing the delivery of laboratories are a global phenomenon. The first chapter of the thesis describes the theoretical background, state-of-the-art, motivation, and objectives. In this chapter, the concepts related to remote laboratories are also outlined.

Chapter 2 describes the building of a multi-peripheral PSoC 6-based development board as the first step in the development of a software-configurable hardware system. The chapter also describes the creation of the printed circuit board and circuit for the prototyped applications, which are provided as design examples. The chapter outlines the steps taken to design the student board, initially utilizing Proteus and Voltera. The CYBLE-416045-02 EZ-BLETM creation module's integration and connection to several peripherals, including Pmod connectors, RGBW LEDs, serial connectivity, BNC connections, and the Arduino stack, are described. It is also covered how to prototype a number of model applications using a PSoC 063 BLE kit and an NI ELVIS II board. Also described are the steps for conducting the experiments for the various applications. These experiments serve as starter projects for the board and demonstrate how to configure both the hardware and software.

The creation of a framework for enabling remote laboratory teaching and learning using expandable hardware and software systems and modules is described in Chapter 3. It describes how to incorporate several experiments in a myRIO using finite state machine coding techniques in LabVIEW and how to reconfigure the myRIO devices from a cloud platform in order to choose particular experiments at any given time. Due to myRIO's memory restrictions, a method is described for transferring data between the myRIO device and the server without installing SystemLink client software on myRIO. Standard designs were employed to show how the platform functions. This chapter discusses the conception and creation of the remote laboratory system using NI My RIO components.

A web-based remote and virtual instrumentation system is developed and described in Chapter 4. G Web development software is used to create WebVI-based interfaces that are hosted on SystemLink servers and the cloud and may be used to access the experiments. To demonstrate how the platforms function, the model experiments were created. To evaluate how well the SystemLink server and SystemLink Cloud function, a performance test was developed.

The significance of the study, its potential to advance science and technology in general, and the business value that may be extracted from it are all discussed in Chapter 5, which ends the thesis. There is a list of the publications and conferences. In this chapter, the thesis is resolved, and opportunities and ideas for further study are provided.
The purpose of this study is to:

- Look into ways to improve STEAM (Science, Technology, Engineering, Arts, and Mathematics) and embedded systems technology teaching and learning both offline and online.
- Given that the COVID-19 pandemic has demonstrated the inadequacy of "face-to-face" training, it is imperative to establish new standards for the didactic process using the intended learning environment. New guidelines for online and distance learning environments are intended by this thesis.
- Provide a platform to train young people for professions in engineering.

1.1 Objectives

1. The development of a software-configurable hardware system through the creation of a multi-peripheral PSoC 6-based board. The system has the following attributes:
    - Software reconfigurability to support hardware peripheral module interchangeability.
    - Physical stack connector for different Arduino shields.
    - Pmod (Peripheral Module Interface) connectors for connecting to various peripheral modules.
    - Serial-LabVIEW-Web communication, BNC connectors, prototyping area, RGBW LED
    - Model experiments for getting started with the board.
2. Create new methodology for remote laboratory learning by utilizing expandable hardware and software systems and modules.
    - Create a method for embedding multiple experiments in a myRIO and reconfiguring the myRIO devices from a cloud platform, allowing you to select a specific experiment at any time.
    - In LabVIEW, use a Finite State Machine (FSM) coding style to embed multiple experiments and choose one at a time.
    - Create a method to transfer data between the myRIO device and the cloud.
    - The data transfer is to be achieved without installing SystemLink client software in myRIO due to memory limitations and the need to achieve enhanced resource management.
3. Create an interactive web-based interface for remote and virtual experiments.
    - Configure an expandable interactive model web user interface to access the experiments.
    - Design a WebVI-based experiment interface in G Web development software and host them on SystemLink servers and the cloud.
    - Host model experiments to illustrate how the platforms work.

- Create a performance test that compares the SystemLink server to SystemLink Cloud.

1.2 Survey findings

A total of 46 former electronic engineering bachelor students were asked to respond to survey questions and some of the responses are shown in Figure 1, Figure 2, and Figure 3.

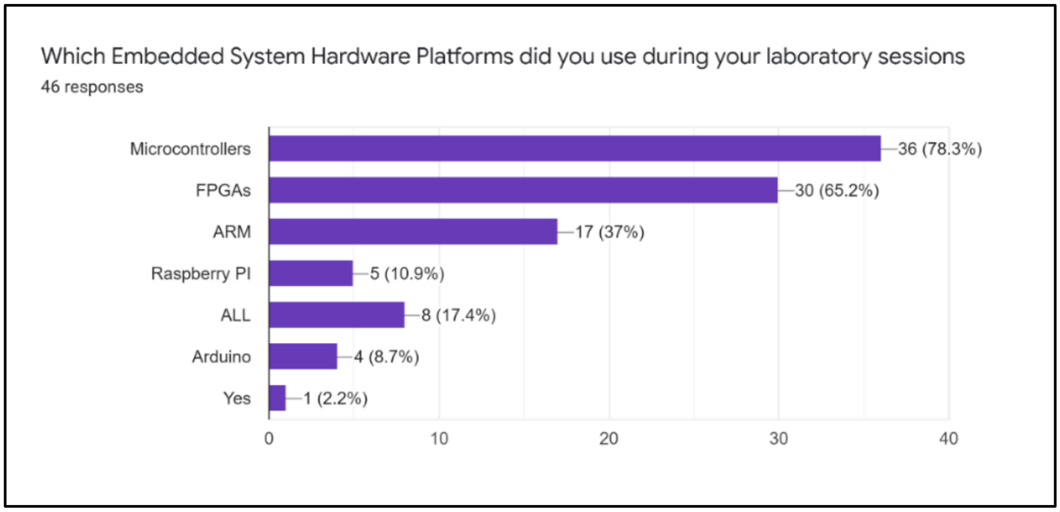

Figure 1: Bar graph showing response for hardware platforms used [original].

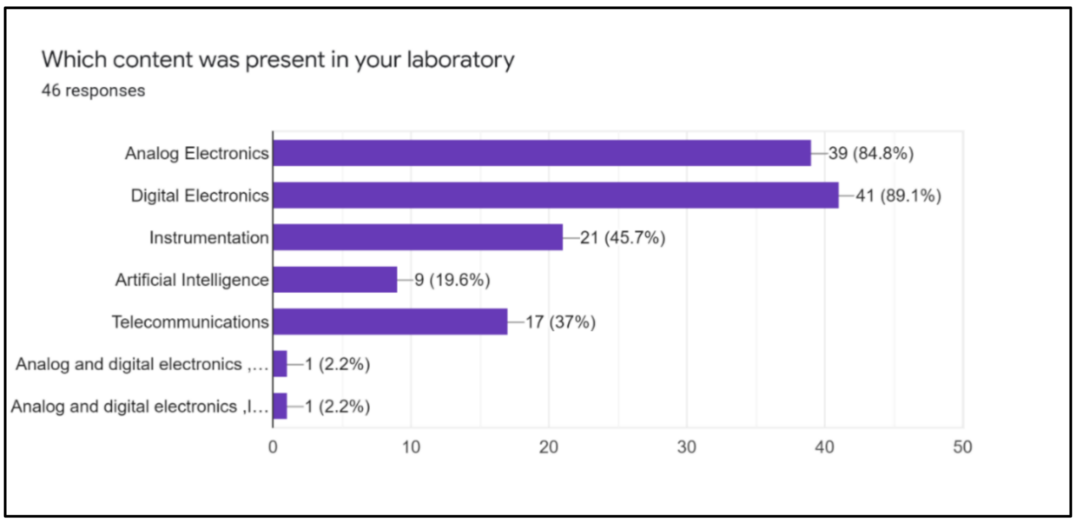

Figure 2: Bar graph showing response for content covered [original].

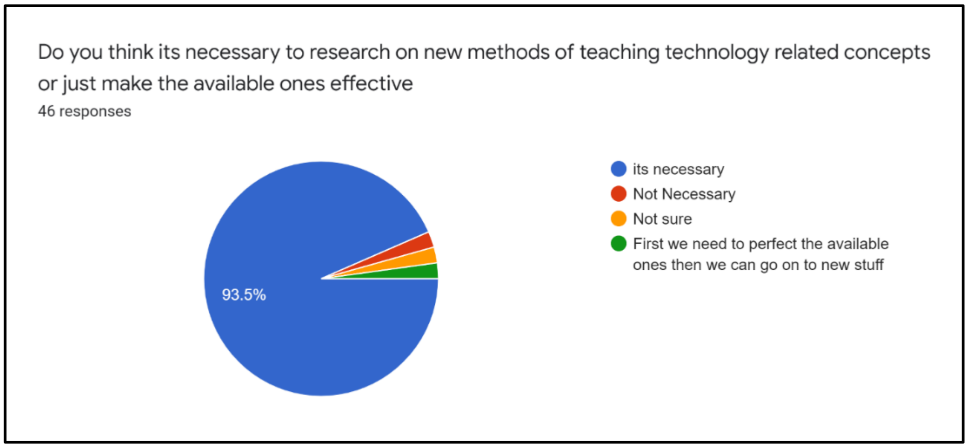

Figure 3: Pie chart showing response on the necessity to research new methods [original].

93.5 of the responses indicated that students felt it was necessary to improve the teaching and learning of laboratory courses. Students also were given a chance to highlight difficulties they faced during their learning time and several challenges were highlighted.

Challenges Highlighted from Survey

- Cost of on-site Lab equipment

With many students being enrolled and encouraged to pursue engineering courses the need for laboratory equipment also increases. Considering the cost associated with standalone electronic instruments, most colleges cannot afford to equip their laboratories to match enrolled numbers.

- Limited laboratory access time

Many of the engineering curriculums are packed with long and intensive courses. The teaching staff must strike a balance between theoretical and practical sessions. The consequence is that with the rising number of students there are bound to be limited hours of practical learning.

- Laboratory equipment's rapid obsolescence

One of the major drawbacks of vendor-based hardware instruments is relative rapid obsolescence as compared to that software-based. Colleges do not have funds for continual replacing of the instruments and hence many times are stuck with old equipment. This equipment might not be compatible with modern technologies.

- Lack of Customized and reconfigurable experiments

Configurable software and hardware offer the possibility to create expandable experiments. Experiments can also be customized to meet course specifications.

Importance of research

The continual research and improvement of embedded design ecosystems for college laboratories and industrial deployment are of paramount importance as highlighted in this section.

- Affordable Platform

A controller platform like the NI myRIO (Reconfigurable input/output real-time embedded evaluation board) is cheap (about 415 Euro) compared to other platforms like the NI educational laboratory virtual instrument Suite (NI Elvis III) going for about 3000 Euro. Although the capabilities of Elvis III are much wider, for educational purposes myRIO still suffices. NI myRIO contains an FPGA and dual-core ARM processor which gives much-needed versatility. Having a cheaper alternative is of paramount importance to underprivileged societies. The cost of some of the available remote laboratory systems is out of reach to many learning institutions. This derails the acquisition of practical skills as in-person laboratory sessions are being discouraged with the occurrence of the covid-19 pandemic.

- Accessibility

Access to the laboratory experiments platforms should be flexible and not restricted to daytime physical attendance. With the traditional laboratory session, physical attendance is mandatory. The increase in technology use in society has led to increased uptake of engineering courses. The STEAM (science, technology, engineering, arts, and mathematics) skill scarcity worldwide, has led to the need for additional engineering graduates to fill the gaps. Recently, Australia's needed for engineers have surpassed what learning Institution can provide, particularly in the civil infrastructure, mining, and manufacturing industries. Meanwhile, the United States Bureau of Labor Statistics forecasts that approximately 140,000 new engineering vacancies will be generated by 2026 in the United States alone, translating to a high demand for future engineering graduates. Considering this increasing expertise gap, it is significant that prospective engineers are capable to exploit their well-balanced and advanced knowledge an engineering bachelor's degree is a good entry point to achieve engineering prowess to help you do this [38]. All this put the engineering laboratory under intense pressure to re-equip and accommodate many students which put a strain on space allocation and budgetary requirements. Remote engineering becomes the means of escape from this quagmire and consequently solves the resource shortage problem.

- Configurability

  The laboratory platform designed should be flexible and adapt to changes for a seeable future to guard against rapid equipment obsolescence.

- Modularity

3 The experimental board will consist of various modules. The modules are proposed to be detachable and electrically separated to increase the board flexibility and students can perform different experiments simultaneously. Modules may be unique to certain experiments.

- Standardization

The goal is to confirm the same standards for some laboratory work. The laboratory work done in one part of the world can be recognized in another.

- Rapid prototyping

In all this, the research should enable a rapid prototyping mechanism because technology advancement is moving at an alarming speed. Every design done in a laboratory should expeditiously move from concept to deployment.

- Reference design use

This is the use of the existing technical framework of the crucial elements of a system. The frame can be modified appropriately and customized for the intended application. This is especially important in the embedded design ecosystem. These reference designs assist clients by trimming the development procedure, consequently accelerating time to market leading to design cost reduction [39]. NI myRIO is a far-reaching tool that put the capabilities of NI LabVIEW RIO architecture, an internationally accepted, industry-attested hardware/software design technique, in the students' hands.

- Pre-loaded applications

Pre-loaded application codes help students to conduct experiments and understand concepts before they can make their designs. These laboratories can be conducted offline.

- Remote control capabilities

Remote access capabilities eliminate the issue of physical appearance in a laboratory and crowding on the few labs' equipment available. Students can work in the comfort of their homes. Students can dedicate more time to the practical aspect of their study and consequently enhance their understanding.

- Multiuser enabled

Several users should be able to access the platform simultaneously. This facility helps students work in groups promoting teamwork.

- Virtual instrumentation

The front panel indicators in LabVIEW are so versatile and can be customized to suit a particular design and application and work as virtual instruments.

- One-stop laboratory platform

Many are laboratory focused on certain concepts or topics. This platform seeks to have a one-stop board for an electronic engineering project. This can be achieved by utilizing the following characteristics:

- Mixed (analog and Digital) signal handling Capabilities.
- Configurability.
- Modularity.
- External device Interfacing.

The laboratory is deemed by various researchers to play a significant part in science education. In engineering, hands-on learning exposure is as essential a portion of the student's learning activity as the theoretical component of a given course. With the advent of automation in higher education, remote and simulated laboratories have become an alternative to face-to-face laboratories. This section types of laboratory models that can be implemented by faculties. Figure 4 presents a categorization of remote laboratories and their hybrids, based on the locations of the experimenter and the experiment.

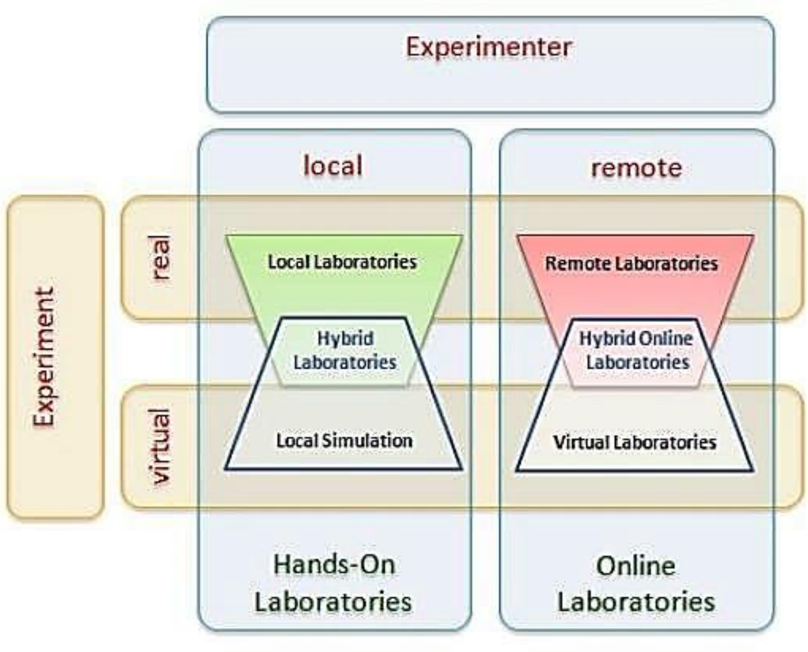

Figure 4: Laboratory models

2 SOFTWARE-RECONFIGURABLE HARDWARE - MULTI PERIPHERAL DEVELOPMENT BOARD

The section outlines the development of a software-reconfigurable hardware system. The student board contains Pmod (Peripheral Module Interface) connectors for connecting numerous peripheral modules as well as an Arduino-compatible stack connector suitable for various shields. The board can be reconfigured by software, enabling hardware interchange at the connectors for peripheral modules. Additionally, the board supports serial connectivity that may be used to connect to the internet using LabVIEW. The other physical peripherals are an RGBW LED, BNC connectors, and a prototype space. This board demonstrates hardware reconfigurability by enabling interchangeable connections to various sensors using the same protocol over a single Pmod interface. Software component configuration is possible with PSoC Creator. And reconfigurability is possible when a pre-configured PSoC component is further configured through LabVIEW during runtime.

Figure 5 shows the components and concepts that were combined to form the reconfigurable development board.

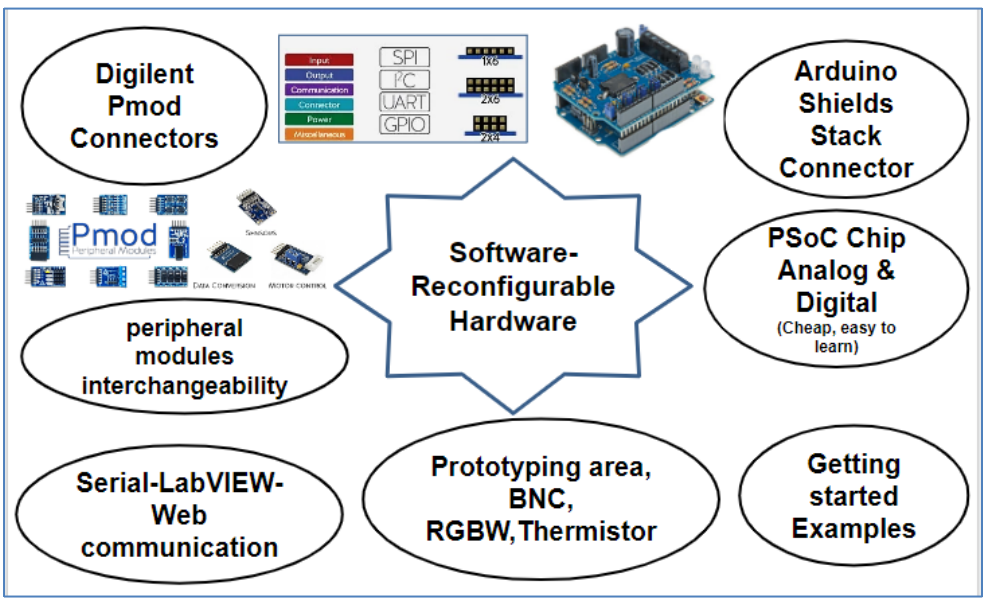

Figure 5: Hardware system reconfigurable from software

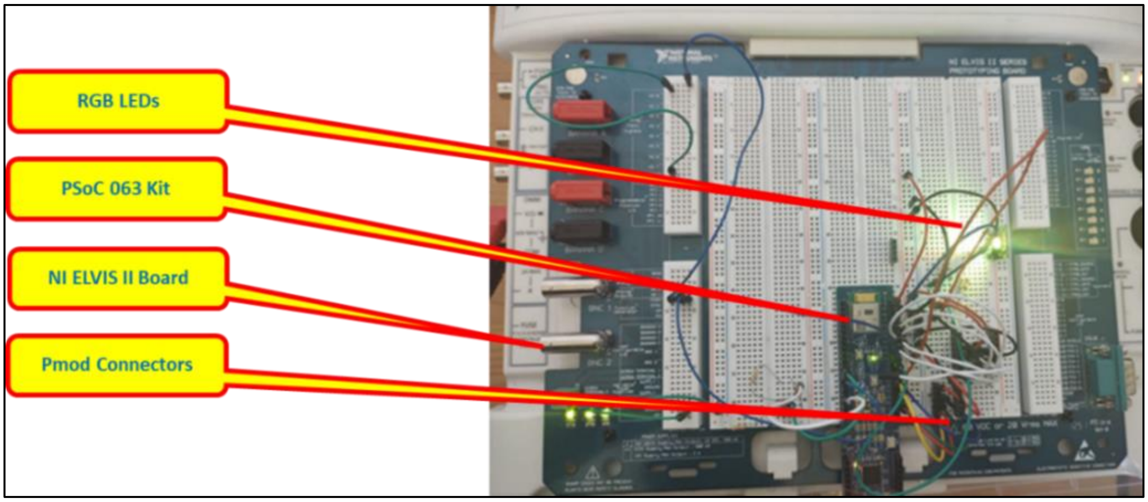

Figure 6: NI ELVIS circuit prototyping

All the example applications were prototyped on the NI ELVIS II board (Figure 6).

The student development board has the following attributes and capabilities:

- CYBLE-416045-02 modular development board.
- Stand-alone take-home kit for electronic applications.
- Arduino expansion platform.
- Motherboard for Digilent's Pmod modules
- Development platform for MiniSmartGPU test and application.
- Design small digital and analog electronic circuits.
- Sensing and measuring environmental Signals (IoT adaptable)
- Bluetooth PWM in RGBW LED lighting applications.
- Generate, process, measure, and analyze analog signals
- Prototype a small device using touch-screen capabilities
- Reconfigure the processing unit.

Learning by experience is a crucial component of modern engineering education. In recent years, due to rapid technological developments, virtual and remote and virtual laboratories are used on a large scale. This section presented the design and development of a student board that can be used by both teachers and students for educational purposes. The board is an inexpensive mixed-signal platform to teach various concepts in electronics embedded system laboratories, such as:

- Communication protocols (UART, SPI, I2C)
- Analog Electronics (amplification, ADC, DAC)
- Digital Electronics (Logic, PWM, FSMs)

The following hardware is available on the Student PSoC board:

- PSoC CYBLE-416045-02 EZ-BLE Creator Module – this is the core controller of the student board.
- Micro B USB 2.0 Receptacle Connector 5 -CONN RCPT USB2.0 MICRO B SMD R/A and USB Bridge-IC USB TO I2C BRIDGE DEVICE 14SO - provides USB-UART interface and connection
- The PMOD connector – this allows connection to Digilent's Pmod peripheral modules.
- Programming Header – For Programming CYBLE Module.
- Prototyping area – provides additional resources usable for other complex experiments and applications.
- One Arduino Uno expansion header (Uno R3 compatibility), can relate to Arduino shields

- Design Process

The CYBLE-416045-02 EZ-BLE™ Creator module is the choice for the design of the student's take-home board because:

- It can manage mixed signals and is inexpensive compared to options like FPGAs.
- Offers flexibility through hardware and software reconfigurability.
- Module chip is BLE capable, thus conforming to current IoT trends.

The capability of the designed board has been demonstrated by developing several applications, which the following two are presented in this section:

1. LabVIEW and Bluetooth-based control of RGBW LED intensity.
2. CySmart Android application control of RGB LED using Bluetooth Low Energy (BLE).
3. Voltage divider thermistor-based circuit.
4. Variable frequency PSoC-based signal generation with LabVIEW manipulation and display.

The several demo experimental applications prototyped on the NI ELVIS II board are for familiarization with the student board. The board's subsystems are outlined as follows:

- The Power Supply

The power supply (Figure 7) has three power options, the 12V, 5V, and 3.3 power supplies. This arrangement increases the range of applications that can be implemented, as different power requirements are catered for.

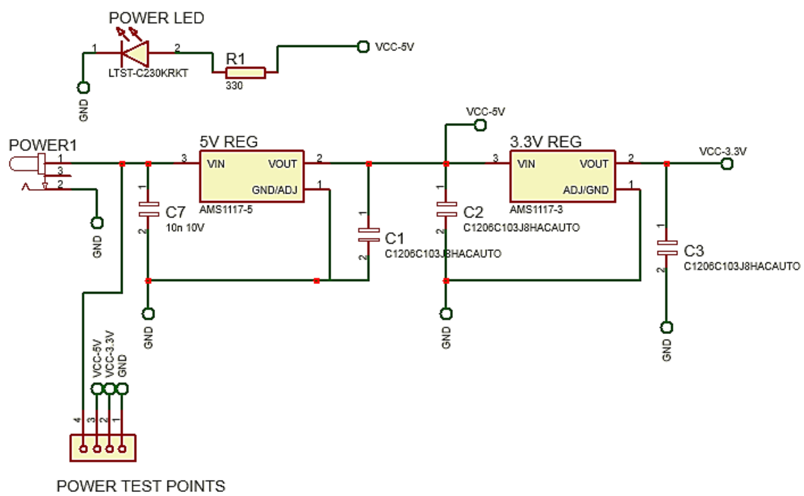

Figure 7: The power supply [original].

- The USB-UART interface

The USB connector (Figure 8) offers power to the USB-UART chip, and it enables the board-to-computer connection that is crucial for LabVIEW serial communication with the board.

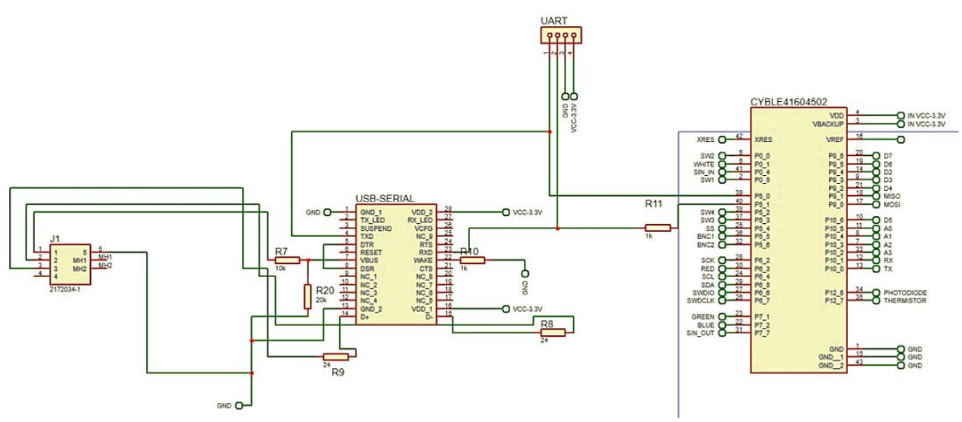

Figure 8: The USB-UART interface [original].

- The CYBLE module and peripherals

The CYBLE (Figure 9) is the central controller of the board, and it connects to several peripherals. The peripherals include:

- BNC connectors: These acquire or transmit signals to and from external sources or nodes.
- Arduino stack: The Arduino Uno R3 can be connected in a stack arrangement on the student board and can be utilized to increase the functionality of the board through the PSoC-Arduino connection.

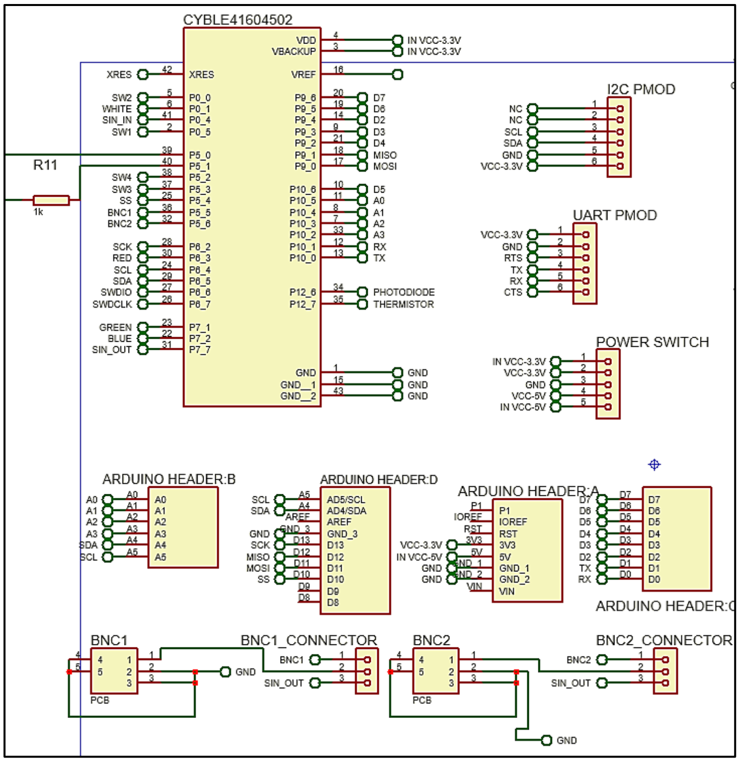

Figure 9: The CYBLE module and peripherals [original].

- The RGBW Display

Figure 10 shows the circuit for the RGBW LED display which is controlled from LabVIEW truth the UART interface.

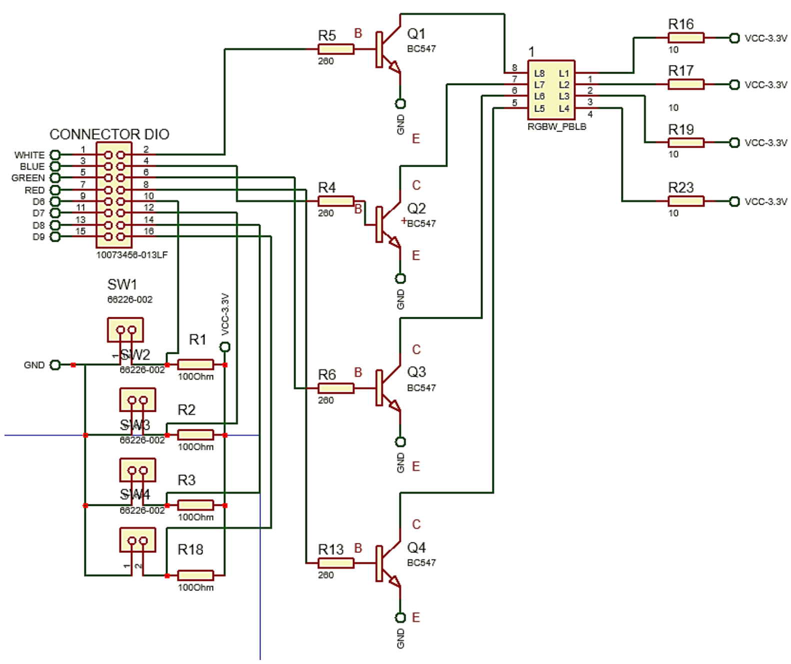

Figure 10: The RGBW display circuit [original].

- Thermistor and Photodiode circuits

Thermistor and photodiode circuits (Figure 11) are included as demo experiments to kick-start students' familiarization with the board functionality.

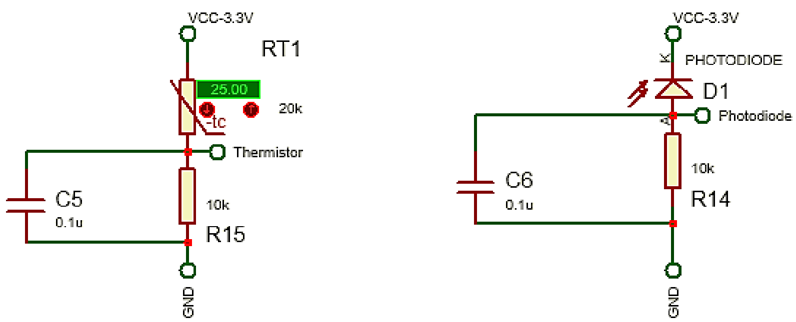

Figure 11: Thermistor and photodiode circuits [original].

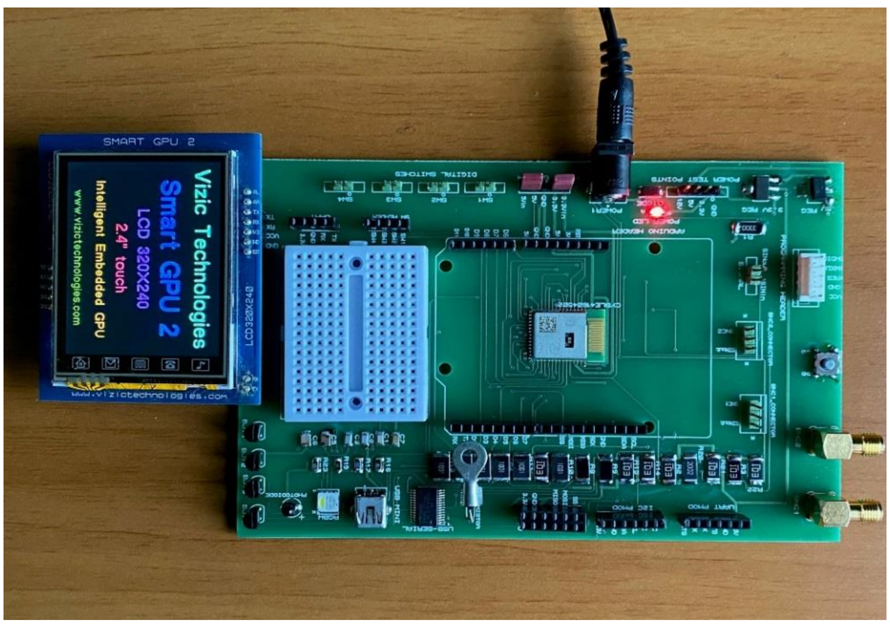

Figure 12: The PSoC module-based development board [original]

- PSoC Security Considerations

Depending on the application, PSoC provides a range of built-in features to secure devices and communication. For the goals of this study, cloud and wireless communication like Bluetooth require protection. Without a separate secure element device, designers may easily integrate security onto a single chip using PSoC 6 MCUs. When securing a PSoC-based system, the following considerations should be made:

- Guard OEM (original equipment manufacturer) intellectual property, including codes, data, and keys.

- Safeguard end-user keys and data
- Verify code integrity (using a hash or cyclic redundancy check).
- Authenticate the source of code (signing).
- Prevent illegal use of hardware.
- Separate the memory spaces of the two CPUs (dual core).
- Safeguard data sent to and from the device.

A customized secured system can be built using the security features of PSoCTM 6 MCUs. Most security requirements can be met by securing a system with one feature or a combination of features. The user can choose from the list based on their needs.

- Programming the secure elements into the CM0+ core which is more secure that the CM4+ core.
- eFuse- Storing the system hash values and security features in the unchangeable efuse blocks.
- Device lifecycle stage – It specifies how the device boots up and what security features, such as Data at Rest (DAR), to enable: methods that stop attackers from accessing non-volatile storage, even if they have physical access. Data erasure and encryption are typical methods.
- Secured boot sequence - when the hardware is pre-configured to authenticate code using trusted security credentials.
- Chain of Trust (CoT)- This requires that the device ROM be linked to the validation of the user application code. The user's public key that is saved in SFlash is used to verify the code. For the SFlash region, a hash is generated and saved in eFuse. The boot will fail if there are any eFuse, public key, or user code modifications.
- Code signing – software and apps that have a digital signature and confirm that the associated code has not been modified since it was signed
- Protection units and protection context - These shields the code and data from various bus masters or isolate them from them. Additionally, they are employed to protect hardware like flash and effuse programming. Additionally, the user has the option to secure GPIOs or communication ports.
- Debug port configuration - The debug port is first utilized for user application development and debugging; however, it should be deactivated once the device reaches the SECURE lifecycle phase.

2.1 The development board Innovation

- Physical stack connector for different Arduino shields.
- Pmod (Peripheral module interface) connectors for connecting to various peripheral modules.
- Software reconfigurability to support hardware peripheral modules interchangeability.
- Serial-LabVIEW-Web communication, BNC connectors, Prototyping area, RGBW LED
- Model Experiments for getting started with the board.

2.2 Reasons to use the development board

- A CYBLE-BLE module brings analog and digital concepts in one place at a relatively lower cost than a comparable FPGA plus MCU combination.
- combines the software configurability provided by the PSoC ecosystem and LabVIEW,
- and the hardware interchangeability provided by Digilent Pmod connectors
- The PSoC Creator IDE graphical designing has a gentle learning curve than FPGA implementations hence the board provides for a rapid concept-to-development cycle.
- At the bachelor level the student board caters to the following concepts:
  - Analog and digital electronics.
  - Embedded systems related concepts (ADC, DAC, PWM, Op-amps)
  - Communication Protocols (UART, I2C, SPI)

3 HARDWARE AND SOFTWARE EXPANDABLE SYSTEM - REMOTE LABORATORY PLATFORM DEVELOPMENT

The creation of a novel technology and methodology to create a remote laboratory learning platform is described in this chapter. The Platforms combine LabVIEW, NI SystemLink, and myRIO devices' expandability. The utilization of finite state machine coding in LabVIEW to Embed multiple experiments in a myRIO and devise a method to reconfigure the myRIO devices from a cloud platform thereby selecting a specific experiment per given time was detailed. A method to transfer data between the myRIO device and the without installing SystemLink client software in myRIO due to memory limitation is outlined. Typical designs are implemented to illustrate the platform's functioning. The design and development of the remote laboratory system powered by NI My RIO devices are covered in this chapter. Students have access to a web-based user interface using the cloud-based, extendable, and adaptable remote laboratory to conduct experiments. Multiple myRIO devices are configured to run multiple experiments each. A single state can contain multiple experiments, and a finite state machine is used to select different experiments. The System Link cloud and System Link server are used to hosting the web-based virtual instrument interfaces for laboratories. A user-friendly interface that covers fundamental analog electronics, digital electronics, and the Internet of things was created to assist students in understanding key electronic concepts. For students to have access to a wide variety of experiments online, real, and virtual experiments were combined. The results of an experiment being run on the apparatus can be checked by the teacher. The system can be expanded because each pin in myRIO can be utilized as a channel for an experiment. A specific experiment can be selected and conducted while other experiments are on hold because of the finite state machine-based coding technique. The experiments platform is a hybrid online laboratory since it is real, virtual, and remote. The developed remote lab platform can cover electronic engineering concepts mainly at the bachelor level and to a lesser extent at the master's level. The capability of the laboratory platform is not limited to demonstrated functionality but can be extended and reconfigured to suit changing needs. The provided laboratory web interface is a conceptual model design.

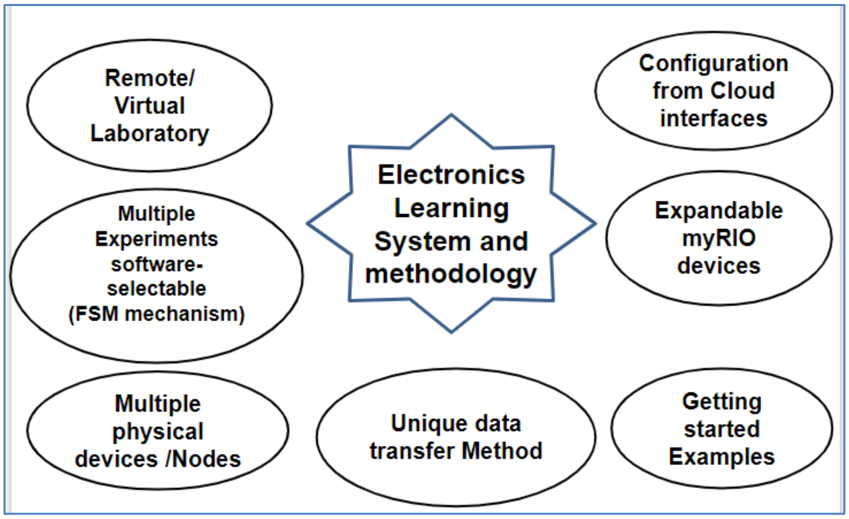

Figure 13: Remote laboratory platform attributes

Figure 13 shows the components and concepts that were combined to form the expandable remote laboratory platform.

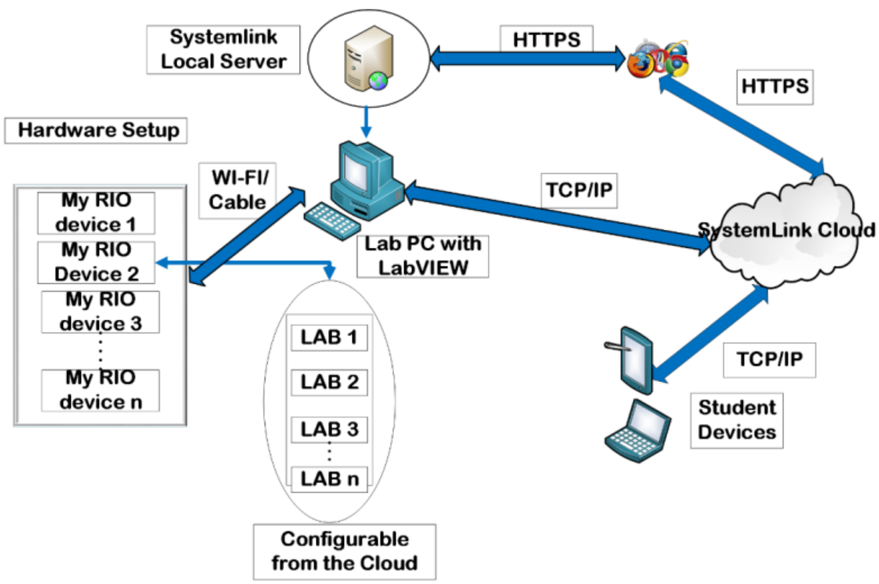

Figure 14: Remote laboratory system connectivity

MyRIO devices are connected to the computer in the lab through either a USB cable or Wi-Fi protocol. A finite state machine based VI is deployed in each myRIO device (Figure 18). Any number of states may be present in an FSM. Additionally, there are VIs that run on a PC and interact with Vis in myRIO devices and SystemLink cloud tags. Global variables are used by the LabVIEW FSM code deployed in myRIO devices to transfer data to and from the code running on the PC. Between the program deployed in the myRIO device and the online user interface, the code running on the PC serves as a data transmission middleman. Data from the myRIO device is received by the intermediary LabVIEW code running on the PC using global variables, and it is then transferred to the web interface via SystemLink tags. An application programming interface (API) Key and cloud server URL must be defined on the open configuration VI in LabVIEW for data to be transferred from LabVIEW to SystemLink Cloud. Each SystemLink tag has a distinct name and a data type, and they are created in the SystemLink cloud and SystemLink server. In LabVIEW, the tag name and data type are compared and declared on a tag VI (Figure 15). Specifying the server URL, API key and related SystemLink tags enables data transfer from the PC to the Web VI located on the SystemLink Cloud.

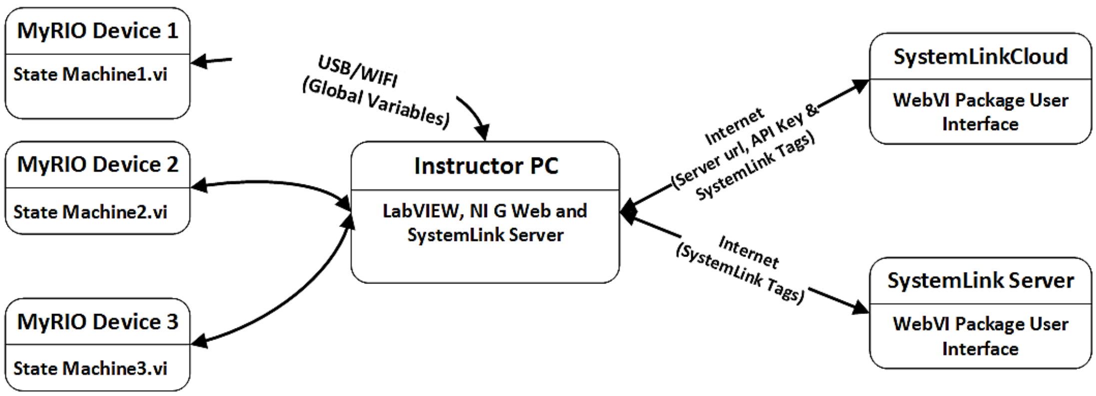

Figure 15: Laboratory flow diagram

Figure 16: Experimental setup

On a single tab of a web interface, the interfaces are visible. Experiment Codes from the same state-run separately from one another. Different devices' LabVIEW code for Finite State Machines runs separately from one another (Figure 17).

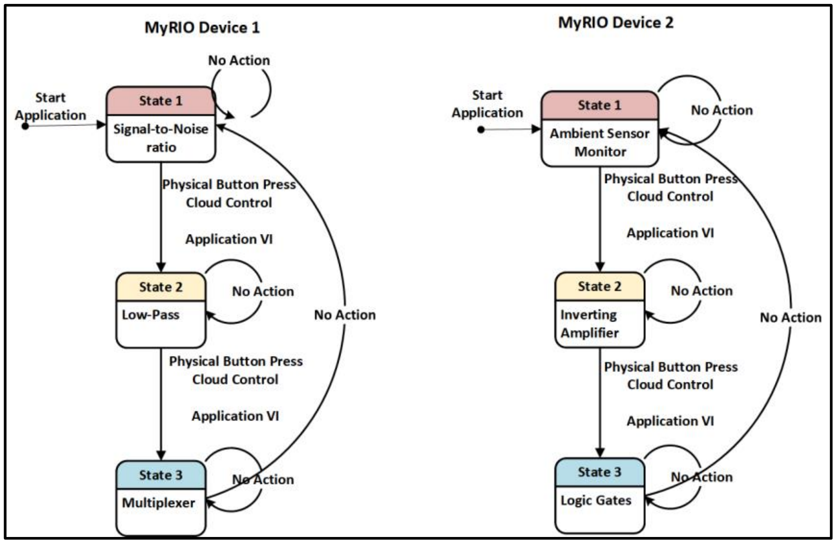

Figure 17: Finite System Machine architecture

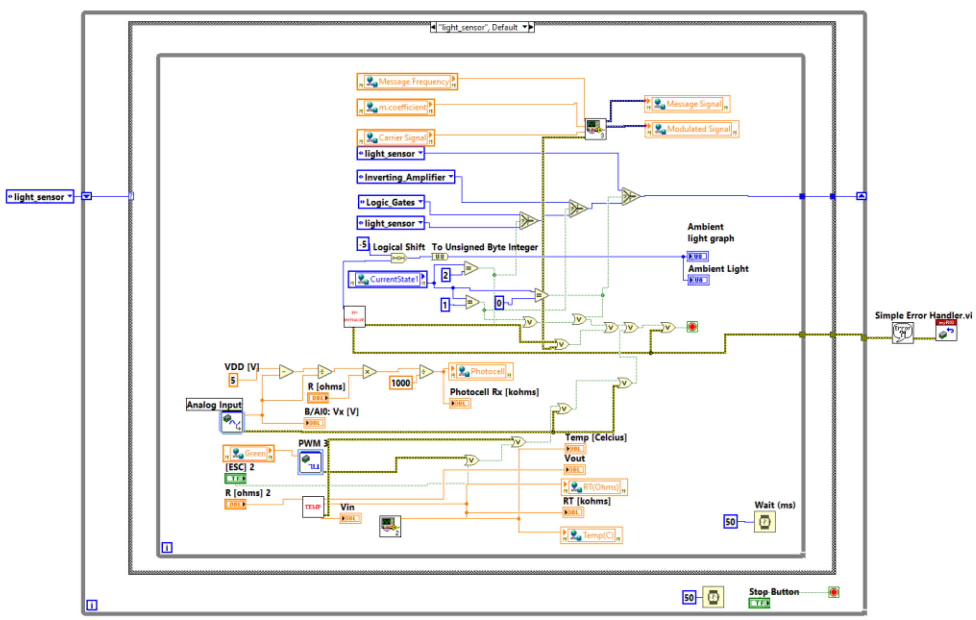

Figure 18: Finite State machine code

A WebVI hosted on a SystemLink server or in the SystemLink cloud receives the data from LabVIEW. The LabVIEW-compatible graphical language used in NI G Web development tools is utilized to create the WebVI. The WebVI uses the same settings as LabVIEW to receive data from tags.

3.1 The Laboratory Platform Innovation

- Unique and memory-saving data transfer mechanism using global variables and SystemLink tags.
- Reconfigurability from the SystemLink cloud interface, enabled by the FSM coding technique, which permits the selection or loading of specific experiments to run while others are on hold.
- Multiple experiments deployment within each myRIO device enabled by a finite state machine (FSM) based coding.
- Designed WebVI-based interfaces using the G Web development tool, and the hosting on SystemLink server and the cloud.
- Comparison of the data logging frequencies of the SystemLink server and the SystemLink cloud.
- In contrast to other systems that just offer computer-to-lab platform connectivity, this platform's special feature includes student-to-teacher platform interaction

3.2 Reasons to use the Laboratory platform

- The Platform is reconfigurable and expandable to accommodate most electronic engineering laboratories.
- The MyRIO device is capable to handle basic to complex concepts like machine vision.
- The platform construction and network format provide an accelerated user-to-developer path for students.
- In contrast to other systems that just offer computer-to-lab platform connectivity, this platform's special feature includes student board-to-teacher platform interaction
- At the bachelor and master level the student board caters to the following concepts:
    - Analog and analog electronics
    - Mechatronics and embedded systems
    - Machine vision

4 INTERACTIVE WEB-BASED INTERFACE FOR REMOTE AND VIRTUAL EXPERIMENTS

In this section, the idea of remote virtual instrumentation is described through the creation of a model online user interface for accessing the experiments. These interfaces are created using WebVI-based experiment design in G Web development software and hosted on the SystemLink server and cloud. The model experiments were designed to illustrate how the platforms work. A performance test was formulated to make a comparison between the SystemLink server and SystemLink Cloud.

The creation of a web interface is divided into two parts:

- G Web VI designing
- Hosting on SystemLink Local Server and cloud.

At the bachelor and master levels the student board caters to the following concepts in Internet of Things:

- Wi-Fi connection configuration.
- LabVIEW Hierarchical design and global variable connection.
- SystemLink Tag and message communication.
- WebVIs design and Hosting on the web.

Few experiments were selected to demonstrate the remote laboratory platform ecosystem's proof of concept. One can access the website at https://sites.google.com/view/cvtc-lab/home. Figure 19 experiments list webpage. The page offers links to several labs. Both remote experiments using myRIO and virtual experiments using Multisim are hosted on the website.

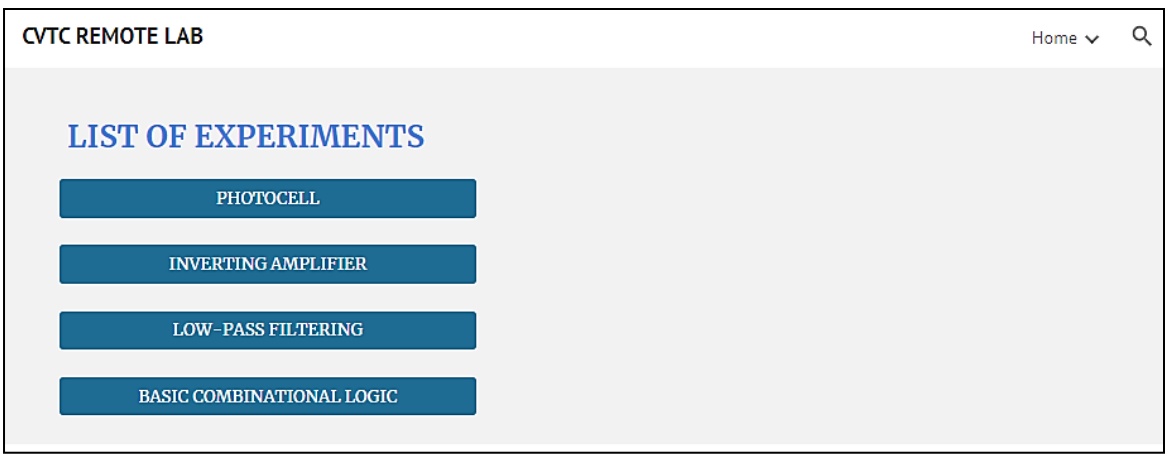

Figure 19: Experiments list webpage

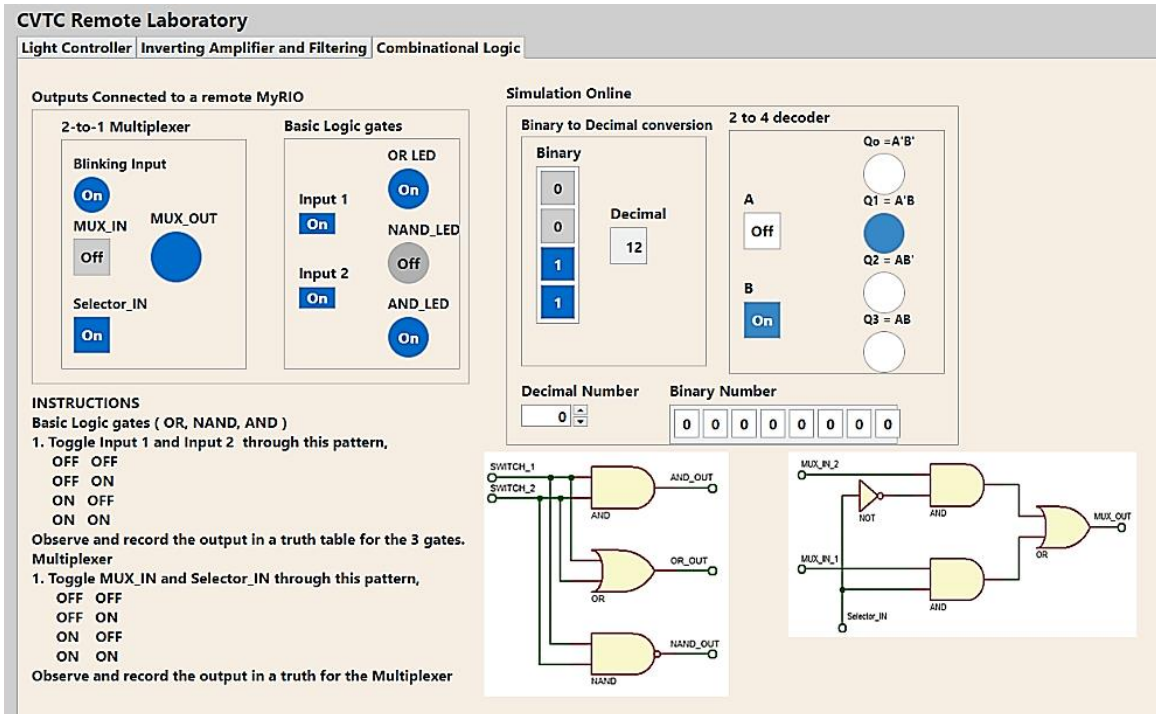

Figure 20: Digital Electronics experiments web interface

Figure 20 shows an example experiment interface that demonstrates the function of a 2-to-1 multiplexer and fundamental logic gates operate. Three logic gates-an OR gate, AND gate, and a NAND gate-make up the configuration for logic gates. Three outputs and two inputs that can be toggled between 00 and 11 are attached to the logic gates. Both the web interface and the lab's myRIO device LED display each logic gate output. After this experiment the students will be able to:

- Recognize the features of AND, OR, NAND, and a 2-to-1 multiplexer.
- Comprehend and use truth tables.
- Recognize that the hardware has been configured to reflect the changes.

The ultimate goal of this thesis is to enable student to have a rapid concept-to- development in creating remote systems and the students will:

- Recognize SystemLink's contribution to data storage and transfer.
- Be familiar with reading and writing SystemLink tags.
- Recognize the connection between a tag and its path.
- Understand how tags, indications, and controls are related.
- Developed VIs to communicate with the SystemLink server (Figure 21).

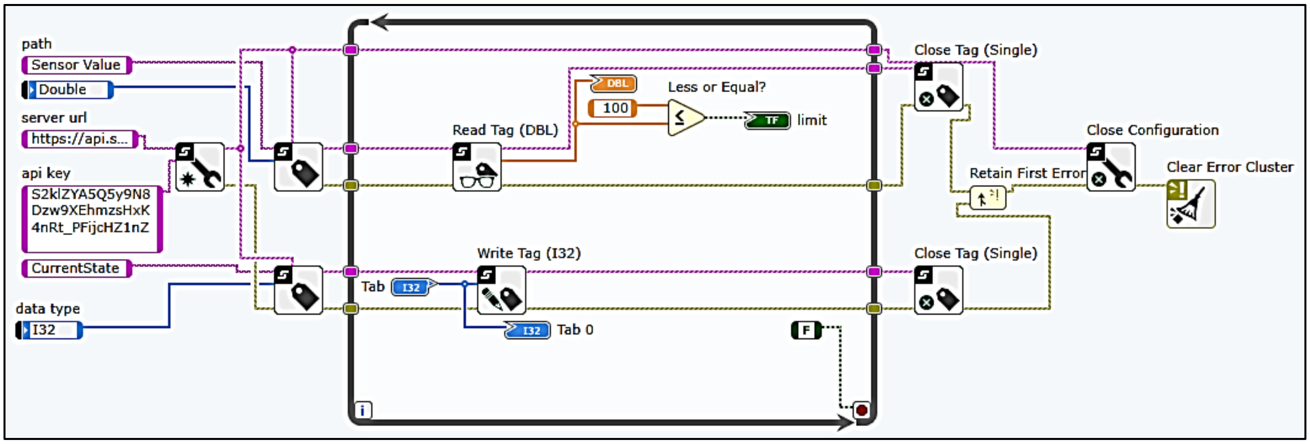

Figure 21: A typical WebVI block diagram

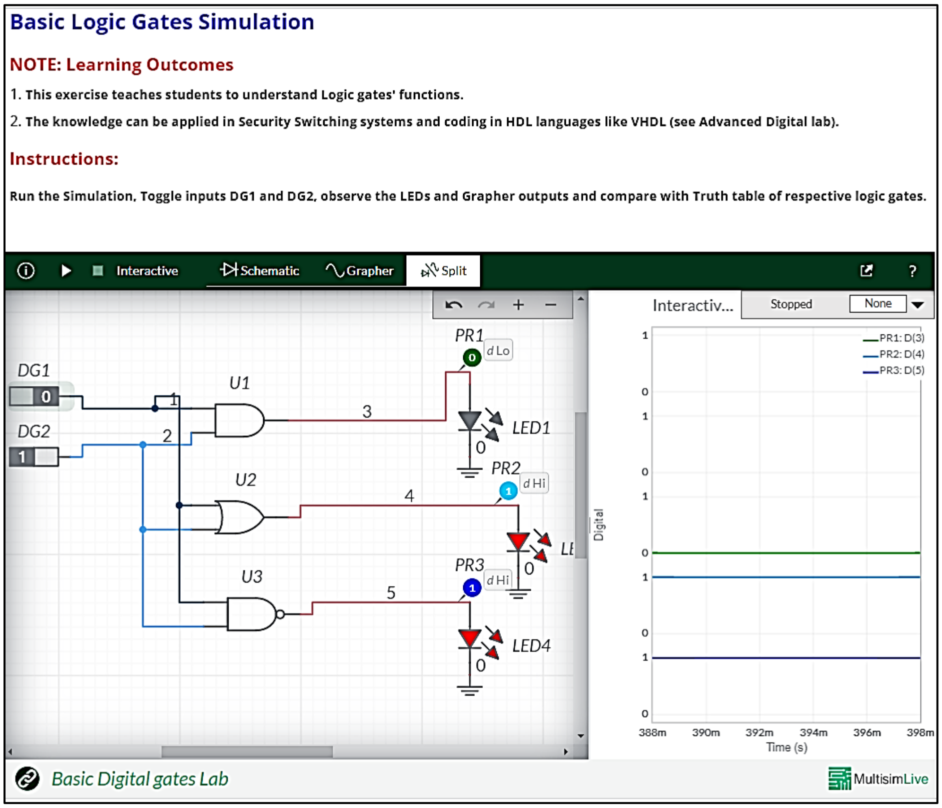

Figure 22: Multisim live Logic Gates Simulation interface

The platform was successful in hosting experiments and showing how to learn of some of the basic electronics engineering concepts. The interfaces including Multisim Live (Figure 22) can be accessed and manipulated from any connected device screen. The Laboratory platform needs to be integrated into a learning management system (LMS) for better performance. An LMS system will help manage students' slots and queuing. Also, ways should be found to increase the application count.

5 CONCLUSION, ORIGINAL CONTRIBUTIONS AND RESEARCH POTENTIAL

The study was carried out by the Transylvania University of Brasov's Centre for Valorization and Transfer of Competence (CVTC), which owing to its current president Prof Doru URSUTIU enjoys productive working relationships with Cypress-Infineon, Diligent, and NI Romania. These partners provided a mix of hardware, software, and reference designs that were used to create the student board and the teacher's platform page model. The main advantage was the capacity to build around the frameworks of the available hardware and software resources. The integration of development boards is a novel idea because it integrates the functionality of MCU and FPGA applications. Additionally, it merges the PSoC module's reconfigurability and the hardware interchangeability of Pmod modules onto a single platform. A strong belief that it will work for the post-COVID age is also fostered by the impeccable hands-on experience it gives students. A PSoC BLE board, which costs around 80 US dollars and is more easily programmable than FPGA-based boards, which normally cost at least 120 US dollars, is a preferable choice for intermediate studies. The laboratory platform was built on the NI myRIO hardware and offers a valuable experimental online platform for electronic engineering lab activities. The platform's design permits the replacement of other sensors due to the versatility and flexibility of the Pmod connections. Prototyping connections are made simple by the integrated sensors provided by the Digilent company. The interior of the myRIO device expansion port (MXP) connector is protected, but students concentrate on top-level circuit design. The ARM processor and FPGA chip in myRIO make it possible to implement many capabilities of varying complexity.

For those learning engineering courses, LabVIEW is excellent since it provides a graphical programming environment. The graphical programming approach is advantageous for engineering students who are accustomed to presenting answers via process diagrams. The program also provides a simple method for designing FPGAs by abstracting numerous details and allowing students to focus on their algorithms. The SystemLink environment offers a suitable platform for conducting online experiments, using SystemLink cloud services, and using the Dashboard mobile application. This laboratory platform's integration of LabVIEW SystemLink server, SystemLink Cloud, and NI WebVIs creates the ideal ecology for IoT designs and remote labs. The environment is appropriate for students who do not have easy access to expensive laboratory equipment, and it is an excellent platform for distant labs. An LDR camera will also be included so that the students may see the actual devices in action. Student feedback is an ongoing process which can be accessed at: https://forms.gle/Yi1eirAhTxf7CK71A. NI real-time hardware devices with more than 512MB RAM can connect with LabVIEW and SystemLink cloud platform to structure remote educational laboratories and industrial process control. The methodology expressed in this study could be considered as a proof-of-concept, commencing the passion for related projects aiding a wide variety of engineering students worldwide. The need for transmission of information and absorption is facing the challenges of social distancing in the post-SARS-COV2 educational environment, therefore easy-to-program software and hardware and solutions are essential [86]. The thesis managed to contribute knowledge to learning methods in the post-Covid era and how to conduct STEAM classes using a combined platform for hardware and simulated labs. The creation of an extensible, affordable, and adaptable remote platform puts academics' experimentation methods, particularly in the sub-Saharan region, to the test. The issues with insufficient resources might be resolved if institutions collaborate to create strongly integrated platforms for their faculties.

In summary, the systems presented in this thesis are highly recommendable because:

- They offer Rapid Prototyping (quick path from user to creator)
- PSoC is a cheaper option in comparison to FPGA and offers a gentle learning curve.
- They offer student board-to-teacher platform interaction as compared to another system that offers computer to Lab platform interaction.
- In normal operation, myRIO requires maximum power consumption of 14 watts (6-16VDC) and
- Student boards have a maximum consumption of 9W (9VDC) so the power requirements even for solar considerations

5.1 Original Contributions

- **Software-Configurable Multi-Peripheral Board**

1. Created a unique combination and peripheral versatility on a development board
   The integration of the PSoC CYBLE module and the peripherals which include these unique characteristics of the student board.
    - Physical stack connector to connect different Arduino shields.
    - Reconfigurable Pmod (Peripheral module interface) connectors to interface with various peripheral modules.
    - Serial-LabVIEW-Web communication, BNC connectors, Prototyping area, RGBW LED
2. Rapid concept-to-development cycle
    - A CYBLE-BLE module brings analog and digital concepts in one place at a relatively lower cost than a comparable FPGA plus MCU combination. The PSoC Creator IDE graphical designing has a gentle learning curve than FPGA implementations. So, the board provides for a rapid concept-to-development cycle.

3. Software-reconfigurable Hardware

    - Reconfigurability was achieved when a component configured in PSoC creator software was further reconfigured using LabVIEW during run-time for instance when an already configured VDAC's component's frequency was further configured from the LabVIEW interface there by changing the range of input frequency during runtime. The user can also use software to reconfigure sampling time and other aspects of the hardware.

- **Remote Laboratory Platform**

1. Created a method to embed multiple experiments in a myRIO to reconfigure the myRIO devices from a cloud platform thereby selecting a specific experiment per given time.

    - Multiple experiments were embedded in a myRIO device and a method to reconfigure the myRIO devices from a cloud platform was formulated thereby giving the ability to select a specific experiment per given time, this was achieved by utilization of a Finite State Machine (FSM) coding style in LabVIEW

2. Devise a method to transfer data between the myRIO device and the cloud.

    - The data transfer was achieved by utilizing global variables from myRIO to the computer and SystemLink tags from the computer to the cloud. MyRIO device may connect to the SystemLink cloud by installing SystemLink client software, but it has memory limitations. So, a new way was formulated to circumvent the problems

3. The System Expandability

    - The system can be expanded because each pin in myRIO can be utilized as a channel for an experiment. More states can be added to contain more experiments and each state can be configured to hold multiple experiments.

- **Web-Based Remote and Virtual Instrumentation Interface**

1. Created a mechanism to use a web interface to select and run experiments in a remote myRIO device

    - Design WebVI-based experiment Interfaces in G Web development software which are hosted on SystemLink server and cloud and have a feature to select a preferred experiment in remote myRIO devices.

2. Formulate a performance test to compare between SystemLink server and SystemLink Cloud.

    - A test was formulated through LabVIEW to compare the data logging frequency of the SystemLink server and the SystemLink cloud. This comparison could be helpful for time-sensitive applications.

3. Formulated an interaction between a student board and a teacher hardware platform as compared to other systems which offer computer to Lab platform interaction.

- The system developed can offer student board-to-lab platform interaction another original idea that set it apart from the existing laboratory system. The cloud platform is expandable by adding more tabs corresponding to the increase in states running in myRIO.

4. Creativity in Rapid remote system development

   One of the major goals of this platform is to turn users into creators thus after going through the examples given a student should be able to create their remote system and establish communication between hardware and the cloud platform. The students would be able to:

   - Recognize SystemLink's contribution to data storage and transfer.
   - Be familiar with reading and writing SystemLink tags.
   - Recognize the connection between a tag and its path.
   - Understand how tags, indications, and controls are related.
   - Developed VIs to communicate with the SystemLink server.

5.2 Potential of research in technology development

The research has enormous potential in the development of science and technology. The following areas have been identified as development possibilities that can emanate from this study.

1. Universities Collaborative Remote laboratory

   This work gives the possibility of setting up a shared laboratory facility in a country or region, connecting various universities. In this way, hardware costs and license subscriptions are shared among the participants. Different experts from engineering and information technology can come together to have a robust hardware, software, and online learning management system to cater to the learners and teachers and provide scheduling.

   The use of remote technology is not limited to electronic engineering only but can be employed in several fields like medical, automotive or arts fields where customized learning platforms can be set up for remote collaborative learning.

2. Student Board commercial development

   The student board is envisioned to be the optimum template for the commercial version. The skeletal form can be adopted by various departments to suit the environment, range of sensor inputs, and the respective actuators. The idea of reconfigurability in software increases the range and domain of applications of the board and its variants. The commercial version will surely consider upgrading some components used in the prototype but keeping the core template unchanged.

3. Small-scale business and start-up

   This study is beneficial to start-ups and small-scale businesses like miners. Small business can monitor their processes using the easy-to-adapt and configurable system. The simplicity and the relatively low cost can encourage remote technology to be used at these lower levels.

5.3 Further research

To realize a viable, realistic success and continuity of this work, several aspects need further research and improvements are needed.

- One of the suggestions by experts from Africa was to research the suitability of the system for third-world country universities which needs to be compounded with renewable energy backup systems for ease of access to remote areas.
- Another issue is having a miniature, affordable, and low-power-driven electronic device will highly serve its purpose in developing countries.
- The system also needs the inclusion of mobile internet provisions which can enable connection in rural areas. The integration of such a service will enhance the functionality of the system.

BIBLIOGRAPHY

[1] 'Stuck at home, engineers' binge on technical content | Fierce Electronics'. https://www.fierceelectronics.com/electronics/stuck-at-home-engineers-binge-technical-content (accessed Apr. 18, 2022).

[2] C. M. Markan *et al.*, 'Remote Triggered Analog Communication Laboratory for E-Learning', vol. 9, no. 5, p. 8, 2013.

[3] M. E. Auer and D. G. Zutin, *Online Engineering & Internet of Things: Proceedings of the 14th International Conference on Remote Engineering and Virtual Instrumentation REV 2017, ... USA*, 1st ed. Springer Publishing Company, Incorporated, 2017.

[4] A.-S. Khan Pathan, 'Technological advancements and innovations are often detrimental for concerned technology companies', *Int. J. Comput. Appl.*, vol. 40, no. 4, pp. 189–191, Oct. 2018, DOI: 10.1080/1206212X.2018.1515412.

[5] 'What is an Embedded System? Definition and FAQs | HEAVY.AI'. https://www.heavy.ai/technical-glossary/embedded-systems (accessed Apr. 18, 2022).

[6] 'The role of universities in a highly technological age. https://www.universityworldnews.com/post.php?story=20191023081415452 (accessed Apr. 18, 2022).

[7] P. A. Young *et al.*, 'Cultural and Regional Perspectives, p. 62.

[8] R. Huang, J. M. Spector, and J. Yang, *Educational Technology: A Primer for the 21st Century*. Singapore: Springer Singapore, 2019. DOI: 10.1007/978-981-13-6643-7.

[9] L. Stošić, 'THE IMPORTANCE OF EDUCATIONAL TECHNOLOGY IN TEACHING', *Int. J. Cogn. Res. Sci. Eng. Educ.*, vol. 3, no. 1, pp. 111–114, Jun. 2015, DOI: 10.23947/2334-8496-2015-3-1-111-114.

[10] 'Industry 4.0 by IntroBooks Team - Ebook | Scribd'. https://www.scribd.com/book/435016211/Industry-4-0 (accessed Apr. 14, 2022).

[11] 'Fifth Annual Educator Confidence Report Introduces First-Ever Educator Confidence Index, Takes the Pulse of Teacher Sentiment across the United States. https://www.hmhco.com/about-us/press-releases/2019-educator-confidence-report (accessed Apr. 14, 2022).

[12] 'The Top 5 Tech Trends That Will Disrupt Education In 2020 - The EdTech Innovations Everyone Should Watch. https://www.forbes.com/sites/bernardmarr/2020/01/20/the-top-5-tech-trends-that-will-disrupt-education-in-2020the-edtech-innovations-everyone-should-watch/?sh=6f4b70662c5b (accessed Apr. 14, 2022).

[13] 'Trends in Educational Technology for 2020 | InformED'. https://www.opencolleges.edu.au/informed/edtech-integration/trends-educational-technology-2020/ (accessed Apr. 14, 2022).

[14] K. Welbers, E. Konijn, C. Burgers, N. Bij de Vaate, A. Eden, and B. Brugman, 'Gamification as a tool for engaging student learning: A field experiment with a gamified app', *E-Learn. Digit. Media*, vol. 16, pp. 92–109, Mar. 2019, DOI: 10.1177/2042753018818342.

[15] 'Tackling EdTech Solutions for Student and Teacher Wellness | Emerging Education Technologies'. https://www.emergingedtech.com/2020/03/edtech-solutions-student-and-teacher-wellness/ (accessed Apr. 14, 2022).

[16] 'AI Applications in Education'. https://www.forbes.com/sites/cognitiveworld/2019/07/12/ai-applications-in-education/?sh=5f6cb8062a38 (accessed Apr. 14, 2022).

[17] P. C. Kumar, M. Chetty, T. L. Clegg, and J. Vitak, 'Privacy and Security Considerations for Digital Technology Use in Elementary Schools', *Proc. 2019 CHI Conf. Hum. Factors Comput. Syst.*, 2019.

[18] 'Collaboration Tools | Center for Teaching Innovation'. https://teaching.cornell.edu/learning-technologies/collaboration-tools (accessed Apr. 14, 2022).

[19] 'Enterprise potential of mixed reality applications | Deloitte Insights'. https://www2.deloitte.com/us/en/insights/focus/tech-trends/2017/mixed-reality-applications-potential.html (accessed Apr. 14, 2022).

[20] S. Rokhsaritalemi, A. Sadeghi-Niaraki, and S.-M. Choi, 'A Review on Mixed Reality: Current Trends, Challenges, and Prospects', *Appl. Sci.*, vol. 10, no. 2, 2020, doi: 10.3390/app10020636.

[21] O. Mohammed, M. Chkouri, A. Nejjari, and kamal eddine el kadiri, 'Studying and comparing the free e-learning platforms', Oct. 2016, pp. 581–586. DOI: 10.1109/CIST.2016.7804953.

[22] 'What is Computer-Based Learning | IGI Global'. https://www.igi-global.com/dictionary/designing-effective-computer-based-learning/5120 (accessed Jan. 31, 2022).

[23] Busbee Kenneth Leroy and Braunschweig Dave, *Programming Fundamentals : A Modular Structured Approach*. Rebus Community, 2018. [Online]. Available: https://openlibrary-repo.ecampusontario.ca/jspui/handle/123456789/692

[24] 'Electrical CAD (ECAD) Definition | Arena'. https://www.arenasolutions.com/resources/glossary/electrical-cad/ (accessed Feb. 02, 2022).

[25] 'Distance learning, e-learning, online learning, or virtual learning?' https://nesslabs.com/distance-learning-e-learning-online-learning-virtual-learning-difference (accessed May 22, 2022).

[26] J. Wei, D. F. Treagust, M. Mocerino, A. D. Lucey, M. G. Zadnik, and E. D. Lindsay, 'Understanding interactions in face-to-face and remote undergraduate science laboratories: a literature review', *Discip. Interdiscip. Sci. Educ. Res.*, vol. 1, no. 1, p. 14, Dec. 2019, doi: 10.1186/s43031-019-0015-8.

[27] J. R. López Gutiérrez, P. Ponce, and A. Molina, 'Real-Time Power Electronics Laboratory to Strengthen Distance Learning Engineering Education on Smart Grids and Microgrids', *Future Internet*, vol. 13, no. 9, p. 237, Sep. 2021, DOI: 10.3390/fi13090237.

[28] L. F. Z. Rivera and M. M. Larrondo-Petrie, 'Models of remote laboratories and collaborative roles for learning environments', in *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, Madrid, Spain, Feb. 2016, pp. 423–429. DOI: 10.1109/REV.2016.7444517.

[29] L. F. Zapata-Rivera, M. M. Larrondo-Petrie, and C. P. Weinthal, 'Generation of Multiple Interfaces for Hybrid Online Laboratory Experiments based on Smart Laboratory Learning Objects', in *2019 IEEE Frontiers in Education Conference (FIE)*, 2019, pp. 1–8. DOI: 10.1109/FIE43999.2019.9028421.

[30] M. Darwish, H. Amreiz, A. Janbey, and C. C. Marouchos, 'Virtual Power Electronics Labs for Online Teaching', in *2020 55th International Universities Power Engineering Conference (UPEC)*, Sep. 2020, pp. 1–5. DOI: 10.1109/UPEC49904.2020.9209772.

[31] H. N. Quang and T. M. Hoang, 'A low-cost remote laboratory of field programmable gate arrays', in *Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, Bangkok, Thailand, Feb. 2015, pp. 172–176. DOI: 10.1109/REV.2015.7087286.

[32] I. Angulo, J. Garcia-Zubia, P. Orduna, L. Rodriguez-Gil, and A. Villar, 'Integral Remote laboratory for Programmable Logic', in *2019 5th Experiment International Conference (exp.at'19)*, Funchal (Madeira Island), Portugal, Jun. 2019, pp. 253–255. doi: 10.1109/EXPAT.2019.8876561.

[33] A. Flores, M. Raffo, M. Balcazar, and K. Yllahuaman, 'Remote Laboratory for Teaching Digital Design using a VPN and embedded system', in *2021 IEEE XXVIII International Conference on Electronics, Electrical Engineering and Computing (INTERCON)*, Lima, Peru, Aug. 2021, pp. 1–4. doi: 10.1109/INTERCON52678.2021.9532871.

[34] 'Virtual Instrumentation Using LabVIEW [Updated 2022]'. https://mindmajix.com/labview/virtual-instrumentation-using-labview (accessed Apr. 17, 2022).

[35] Chamunorwa, Tinashe, 'Electronics & Embedded Technology Teaching in Universities and Colleges. Survey'. https://docs.google.com/forms/d/1qLEp1eQCdTGc-zKSBO5snvMlFufvEOzqiy3Cu0oc5cY/viewanalytics

[36] 'Why the Demand for Engineering Graduates Is on The Rise | Top Universities'. https://www.topuniversities.com/student-info/careers-advice/why-demand-engineering-graduates-rise (accessed Apr. 17, 2022).

[37] 'Design for an embedded ecosystem'. https://www.electronicsweekly.com/market-sectors/embedded-systems/design-for-an-embedded-ecosystem-2008-05/ (accessed Apr. 17, 2022).

[38] C. Hodges, S. Moore, B. Lockee, T. Trust, and A. Bond, 'The Difference Between Emergency Remote Teaching and Online Learning', p. 12.

[39] Wagdy Sawahel, 'Africa: COVID-19 drives development of online laboratories', Jul. 2020. [Online]. Available: https://www.universityworldnews.com/post.php?story=20200715130543961

[40] W.-S. Soh, 'Experiential Learning Through Remote Electrical Engineering Labs During the COVID-19 Pandemic', in *2021 IEEE International Conference on Engineering, Technology Education (TALE)*, 2021, pp. 01–05. doi: 10.1109/TALE52509.2021.9678756.

[41] S. Kurukunda, C. Trigona, and S. Baglio, 'Laboratory Activity during COVID- 19 as a "Virtual Experience": Restriction or Chance?', in *2020 17th International Multi-Conference on Systems, Signals Devices (SSD)*, 2020, pp. 349–353. doi: 10.1109/SSD49366.2020.9364113.

[42] R. C. Panicker and D. John, 'Fully Remote Project-Based Learning of Hardware/Software Codesign', in *2021 IEEE Frontiers in Education Conference (FIE)*, 2021, pp. 1–5. doi: 10.1109/FIE49875.2021.9637053.

[43] M. V. Ramya, G. K. Purushothama, and K. R. Prakash, 'Design and Implementation of IoT Based Remote Laboratory for Sensor Experiments', 2020.

[44] A. A. Altalbe, 'Performance impact of simulation-based virtual laboratory on engineering students: A case study of Australia virtual system', *IEEE Access*, vol. 7, pp. 177387–177396, 2019.

[45] J. Svatos, J. Holub, J. Fischer, and J. Sobotka, 'Online teaching at CTU in Prague aka university under COVID restrictions', *Meas. Sens.*, vol. 18, p. 100121, 2021.

[46] O. Velihorskyi, M. Khomenko, and I. Nesterov, 'Remote Debugging of Embedded Systems in STM32CubeMonitor', 2020.

[47] W. Kaewmanee, B. Yodwong, S. Sikkabut, M. Phattanasak, and D. Guilbert, 'A New Low-cost Hardware-in-the-Loop Simulator for Control of Power Electronics Systems Laboratory', in *2021 Research, Invention, and Innovation Congress: Innovation Electricals and Electronics (RI2C)*, 2021, pp. 233–237.

[48] T. Vince *et al.*, 'IoT Implementation in Remote Measuring Laboratory VMLab Analyses.', *J Univers Comput Sci*, vol. 26, no. 11, pp. 1402–1421, 2020.

[49] P. Jacko, M. Guzan, and A. Kalinov, 'Remote Microcontroller Scanner Design for STM32 Microcontrollers Used to Distance Education Form', in *2021 IEEE International Conference on Modern Electrical and Energy Systems (MEES)*, 2021, pp. 1–6.

[50] G. R. Alves, A. Marques, and J. Bento da Silva, 'Lab-based Education', in *Ninth International Conference on Technological Ecosystems for Enhancing Multiculturality (TEEM'21)*, 2021, pp. 533–535.

[51] J. Molnár *et al.*, 'Weather Station IoT Educational Model Using Cloud Services.', *J Univers Comput Sci*, vol. 26, no. 11, pp. 1495–1512, 2020.

[52] D. Praselia, A. N. Handayani, S. Wibawanto, S. N. Mustika, W. C. Kurniawan, and R. A. Asmara, 'Design and Development of Online Media Learning on Analog Electronics Course under COVID-19', in *2021 International Conference on Electrical and Information Technology (IEIT)*, 2021, pp. 45–49.

[53] P. Jacko *et al.*, 'Remote IoT Education Laboratory for Microcontrollers Based on the STM32 Chips', *Sensors*, vol. 22, no. 4, p. 1440, 2022.

[54] J. V. Espinoza, W. I. Alama, J. S. Bohórquez, and I. B. Amaya, 'Implementation of a pilot plant for the integral development of remote laboratories', *IEEE Rev. Iberoam. Tecnol. Aprendiz.*, vol. 16, no. 1, pp. 11–20, 2021.

[55] S. Martin, A. Fernandez-Pacheco, J. A. Ruipérez-Valiente, G. Carro, and M. Castro, 'Remote Experimentation Through Arduino-Based Remote Laboratories', *IEEE Rev. Iberoam. Tecnol. Aprendiz.*, vol. 16, no. 2, pp. 180–186, 2021, doi: 10.1109/RITA.2021.3089916.
[56] C. Monzo, G. Cobo, J. A. Morán, E. Santamaría, and D. García-Solórzano, 'Remote Laboratory for Online Engineering Education: The RLAB-UOC-FPGA Case Study', *Electronics*, vol. 10, no. 9, 2021, doi: 10.3390/electronics10091072.
[57] D. Ursutiu, C. Samoila, and J. Bergmans, 'TEMPUS iCo-op, new trends in LabVIEW — MOODLE integration', in *2014 International Conference on Interactive Collaborative Learning (ICL)*, 2014, pp. 685–688. doi: 10.1109/ICL.2014.7017853.
[58] G. A. G. Carreón, P. C. Lugo, and S. A. C. Valencia, 'Teaching Online Laboratory based on Cloud Services', in *2018 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC)*, 2018, pp. 1–6. doi: 10.1109/ROPEC.2018.8661427.
[59] 'IEEE Standard for Networked Smart Learning Objects for Online Laboratories', IEEE. doi: 10.1109/IEEESTD.2019.8723446.
[60] 'CY8CPROTO-063-BLE PSoC 6 BLE Prototyping Board Guide', p. 42.
[61] 'IoT Powered Predictive Maintenance with Cypress' PSoC®6 Microcontroller and Excelon-FRAM'. https://www.rs-online.com/designspark/iot-based-predictive-maintenance-with-cypress-psoc-6-and-excelon-fram (accessed May 01, 2022).
[62] 'Downtime costs UK manufacturers £180bn a year - The Manufacturer'. https://www.themanufacturer.com/articles/machine-downtime-costs-uk-manufacturers-180bn-year/ (accessed May 01, 2022).
[63] 'Bluetooth-Enabled ECG Monitor - Circuit Cellar'. https://circuitcellar.com/research-design-hub/bluetooth-enabled-ecg-monitor/ (accessed May 01, 2022).
[64] Thirusabaresaan Palanivel, 'an introduction to labview', 2021, doi: 10.13140/RG.2.2.25340.05764.
[65] M. K. Idris, J. Qiu, G. W. Melenka, and G. Grau, 'Printing electronics directly onto carbon fiber composites: unmanned aerial vehicle (UAV) wings with integrated heater for de-icing', *Eng. Res. Express*, vol. 2, no. 2, p. 025022, May 2020, doi: 10.1088/2631-8695/ab8e24.
[66] 'CySmart — Bluetooth® LE Test and Debug Tool - Infineon Technologies'. https://www.infineon.com/cms/en/design-support/tools/utilities/wireless-connectivity/cysmart-bluetooth-le-test-and-debug-tool/ (accessed May 01, 2022).
[67] D. Ursutiu, C. Samoila, P. Kane, and F. Altoe, 'Powerful Technologies Together for Engineering Education (PTT for EE)', in *Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, Bangkok, Thailand, Feb. 2015, pp. 113–117. doi: 10.1109/REV.2015.7087274.
[68] T. Chamunorwa, D. Ursutiu, C. Samoila, and H. A. Modran, 'Embedded System Learning Platform for Developing Economies', in *Educating Engineers for Future Industrial Revolutions*, Cham, 2021, pp. 617–627.

[69] H. Almahzumy, F. Ardilla, and B. S. Marta, 'Board PSoC library design and evaluation for mobile robot implementation', in *2017 International Electronics Symposium on Engineering Technology and Applications (IES-ETA)*, 2017, pp. 257–262. doi: 10.1109/ELECSYM.2017.8240413.
[70] C. Court and S. Jose, 'Universal Digital Block (UDB) Editor Guide', no. 001, p. 52.
[71] C. Court and S. Jose, 'CY8CKIT-049-4xxx PSoC® 4 Prototyping Kit Guide', p. 78.
[72] Kael HANSON, 'Digital Electronics Part III : Finite State Machines', *https://www.wisc.edu/*. https://www.physics.wisc.edu/courses/home/spring2021/623/lecture_notes/digital/digital-03.html (accessed Apr. 02, 2022).
[73] A. Somanathan, D. Bhan, N. Salunkhe, J. Joshi, and A. Tambe, 'Implementation and analysis of a FPGA-Programmable SoC interface towards mixed-signal educational platforms', in *2014 International Conference on Circuits, Systems, Communication and Information Technology Applications (CSCITA)*, Mumbai, Maharashtra, India, Apr. 2014, pp. 99–104. doi: 10.1109/CSCITA.2014.6839242.
[74] A. Ravulavaru, *Enterprise Internet of Things handbook: build end-to-end IoT solutions using popular IoT platforms*. 2018.
[75] M. Huba and P. Bistak, 'PocketLab: Next step to Learning, Experimenting and Discovering in Covid Time', in *2020 18th International Conference on Emerging eLearning Technologies and Applications (ICETA)*, Košice, Slovenia, Nov. 2020, pp. 182–186. doi: 10.1109/ICETA51985.2020.9379240.
[76] T. Klinger, C. Kreiter, A. Pester, and C. Madritsch, 'Low-cost Remote Laboratory Concept based on NI myDAQ and NI ELVIS for Electronic Engineering Education', in *2020 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, Apr. 2020, pp. 106–109. doi: 10.1109/EDUCON45650.2020.9125086.
[77] B. Ulrich, 'A modern, versatile and low-cost educational system for teaching DC/DC converter control with analog, digital and mixed-signal methods', in *2017 International Conference on Research and Education in Mechatronics (REM)*, Wolfenbuettel, Germany, Sep. 2017, pp. 1–8. doi: 10.1109/REM.2017.8075234.
[78] T. Chamunorwa, D. Ursuțiu, C. Samoilă, and H. A. Modran, 'Electronic Laboratory Educational Board', p. 10.
[79] 'CYBLE-416045-02 EZ-BLE™ Creator Module', no. 002, p. 60.
[80] T. Chamunorwa, D. Ursuțiu, C. Samoilă, H. Hedesiu, and H. A. Modran, 'Electronic Educational Laboratory Platform for Students', in *Online Engineering and Society 4.0*, vol. 298, M. E. Auer, K. R. Bhimavaram, and X.-G. Yue, Eds. Cham: Springer International Publishing, 2022, pp. 311–322. doi: 10.1007/978-3-030-82529-4_30.
[81] 'Transferring Data Using Tags - SystemLink Data Services for LabVIEW NXG Web Module Manual - National Instruments'. https://www.ni.com/documentation/en/systemlink-data-services/1.0/manual/transfer-tags/ (accessed May 12, 2022).

[83] T. Chamunorwa, H. A. Modran, D. Ursuțiu, C. Samoilă, and H. Hedeșiu, 'Reconfigurable Wireless Sensor Node Remote Laboratory Platform with Cloud Connectivity', *Sensors*, vol. 21, no. 19, p. 6405, Sep. 2021, doi: 10.3390/s21196405.

[84] E. Doering, 'NI myRIO Project Essentials Guide - National Instruments', *https://education.ni.com/*. https://education.ni.com/teach/resources/92/ni-myrio-project-essentials-guide (accessed Nov. 15, 2022).

[86] T. Chamunorwa, H. A. Modran, D. Ursuțiu, C. Samoilă, and H. Hedeșiu, 'Cloud-Based, Expandable— Reconfigurable Remote Laboratory for Electronic Engineering Experiments', *Electronics*, vol. 11, no. 20, 2022, doi: 10.3390/electronics11203292.

ANNEXES

Annex 1 – List of Publications

- ISI journals,

Expandable-Reconfigurable Remote Laboratory for Electronic Engineering Experiments.
Chamunorwa, T.; Modran, H.A.; Ursuțiu, D.; Samoilă, C.; Hedeșiu, H.
Electronics 2022, 11, 3292.
ISSN / eISSN 2079-9292
Web of Science Accession Number: WOS: 000872619000001
https://doi.org/10.3390/electronics11203292

Reconfigurable Wireless Sensor Node Remote Laboratory Platform with Cloud Connectivity.
Chamunorwa, T.; Modran, H.A.; Ursuțiu, D.; Samoilă, C.; Hedeșiu, H.
Sensors 2021, 21, 6405.
ISSN / eISSN 1424-8220
Web of Science Accession Number: WOS: 000710269900001
PubMed ID34640724
https://doi.org/10.3390/s21196405

- International conferences

Embedded System Learning Platform for Developing Economies.
Chamunorwa, T., Ursutiu, D., Samoila, C., Modran, H.A. (2021).
Publisher: Springer, Cham.
https://doi.org/10.1007/978-3-030-68201-9_60

Learning Methods Based on Artificial Intelligence in Educating Engineers for the New Jobs of the 5th Industrial Revolution
Modran, H.A., Ursutiu, D., Samoila, C., Chamunorwa, T. (2021).
Publisher: Springer, Cham.
https://doi.org/10.1007/978-3-030-68201-9_55

Electronic Educational Laboratory Platform for Students
Chamunorwa, T., Ursuțiu, D., Samoilă, C., Hedesiu, H., Modran, H.A. (2022).
Publisher: Springer, Cham.
Special Session Paper Award Winner
https://doi.org/10.1007/978-3-030-82529-4_30

Artificial Intelligence System for Predicting Cardiovascular Diseases Using IoT Devices and Virtual Instrumentation (Student Paper Award Winner)
Modran, H.A., Ursuțiu, D., Samoilă, C., Chamunorwa, T. (2022.

Publisher: Springer, Cham.
https://doi.org/10.1007/978-3-030-82529-4_28

Software Configurable Hardware-Based Remote Laboratory System
Chamunorwa, T., Ursuțiu, D., Samoilă, C., Hedesiu, H., Modran, H.A. (2023).
Publisher Springer, Cham.
https://doi.org/10.1007/978-3-031-17091-1_2

Intelligent IoT Biomedical Bluetooth Data Acquisition System.
Modran, H.A., Ursuțiu, D., Samoila, C., Chamunorwa, T. (2022).
Publisher: Springer, Cham.
https://doi.org/10.1007/978-3-030-96296-8_88

Electronic Laboratory Educational Board
Chamunorwa, T., Ursuțiu, D., Samoila, C., Modran, H.A. (2022).
Publisher: Springer, Cham.
https://doi.org/10.1007/978-3-030-96296-8_89

Work in Progress: Noise Reduction Through Artificial Intelligence Techniques: An Introductory Study
Modran, H.A., Ursuțiu, D., Samoilă, C., Chamunorwa, T. (2023).
Publisher: Springer, Cham.
https://doi.org/10.1007/978-3-031-17091-1_3
Expandable-Reconfigurable Remote Laboratory for Electronic Engineering Experiments.

Chamunorwa, T.; Modran, H.A.; Ursuțiu, D.; Samoilă, C.; Hedeșiu, H.

Journal: **Electronics** 2022, 11, 3292.

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Web of Science Accession Number: WOS: 000872619000001

https://doi.org/10.3390/electronics11203292

Reconfigurable Wireless Sensor Node Remote Laboratory Platform with Cloud Connectivity.

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