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PRACTICAL ASPECTS FOR CREATING USER INTERFACE OF REMOTE ELECTRONICS LABORATORY

The common issues of remote laboratories are highlighted, including user interface and security procedures. Approach of dividing user interface onto two parts (Security subsystem and Experiment subsystem) is proposed. Single-page web application as an optimal form of accessing remote laboratories is defined and justified. Software tools for the implementation of front-end part of remote laboratory are presented. The general view, features and components of the user interface of implemented remote power electronics laboratory are demonstrated.

Keywords: *remote laboratory; user interface; power electronics; web application; Vue.js framework; front-end.*
Fig.: 8. References: 14.

Relevance of the research. The educational process becomes more advanced as the years go by. Thanks to discoveries in various fields, the information brought to students and pupils is filtered through experience so that they can learn actual facts about the world around us. However, the ways in which students can acquire knowledge are also expanding. This is mainly due to the constant development of information technologies (IT) [1].

The development of the IT sphere allows us to use the Internet and various computing devices (computers, laptops, smart TVs, smart phones, etc.) for fast and convenient learning for the average user. You only need to know where and how all necessary materials can be found or accessed with a few clicks or touches of your finger. Thanks to this, any work of art or interesting article can be consumed without leaving home. In addition, the increasing speed of the Internet connection allows us to receive large amounts of data faster, and you can enjoy broadcasts of football matches or livestreams of your favourite YouTube channel in real time. The same can be said about the educational process for pupils and students.

Since its beginnings in ancient times, the educational process has usually been seen as a series of classes where students and pupils attend institutions and meet teachers who share knowledge with young minds. In the absence of modern technologies such as the Internet, other classical ways of acquiring knowledge were impossible, which was crucial in difficult times (during wars, pandemics, etc.), when one could not physically attend classes. The invention of the Internet and the results of IT development are prerequisites for the process of remote learning, where students and teachers contact each other via the global network.

The COVID-19 global pandemic in 2020 proved to us that difficult times, when it is risky to physically attend classes, can happen anytime, anywhere. Since then, remote learning has become a common practice all over the world. It is important to note that in Ukraine today the issues of remote learning are quite important due to the continuing full-scale Russian invasion of Ukraine, which makes the classroom process impossible in some of the regions. Remote learning can be helpful in these cases as it allows professors to teach a large number of geographically dispersed students [2].

Problem statement. One of the most important issues is the quality of remote practical learning. Unlike the theory, the practical part requires interaction with real equipment and devices (mechanisms, wires, etc.), which cannot be done through online meetings in any of the existing software solutions. Students can gain theoretical knowledge in the classroom, but the necessary practical knowledge and experience can only be gained in the laboratory [3]. This is where simulation tools and remote laboratories come into play.

Simulation tools are software that demonstrates how a system or device works using program code and mathematical equations. For example, when a user wants to interact with the Arduino board, the student opens the appropriate simulation tool, which creates this virtual board for the experiments. It is important to note that this virtual board is not physically accessible and exists only as a sequence of logical 0's and 1's.

Like simulation tools, remote laboratories can be used for conducting experiments and investigating physical or electrical phenomena too. However, the hardware that a user interacts with remotely is physically installed somewhere (e.g. in a scientific institute, university or school). Furthermore, these hardware components can be accessed both remotely and physically. Working with a remote board or microcontroller requires a stable and reliable Internet connection, which can be a major problem for those students who live in places with poor Internet coverage.

Remote laboratories have another disadvantage compared to simulation tools, known as limited capacity [4]. This means that each laboratory has a fixed number of users who can access the equipment at the same time. In popular courses where the number of students is very high, this problem should be solved to avoid long queues.

Obviously, there are, many challenges faced by those implementing remote laboratories for accessible distance learning: laboratory capacity, funding, security issues, etc. In this article, issues of user interface design are highlighted and solutions for remote laboratory systems were presented based on a power electronics remote laboratory implemented at Chernihiv Polytechnic National University.

The results of the research on user interfaces of remote laboratories will make the process of remote practical education more flexible and convenient for students.

Analysis of recent research and publications. Having analyzed articles related to remote laboratories, we can say that a significant part of them generally describe how remote laboratories are built, i.e., their structure. The number of materials is high, which imdicates increased interest in the implementation of such laboratories in educational institutions. Some articles highlight the importance of remote laboratories for simplifying the educational process, while another part gives detailed information about possible problems during development. Additionally, some articles provide detailed descriptions of existing types of remote laboratories, which can be very helpful for those who have only started researching this topic.

Xuemin Chen Gangbing Song and Yongpeng Zhang in the article “Virtual and Remote Laboratory Development: A Review” analyzed some of the remote virtual and remote laboratory development tools (Java, Flash, VPN, XML, LabVIEW, Simulink, Matlab, Web 2.0) [5]. The authors also divide the process of remote laboratory development into four parts: computer hardware and software, data digitization and collection, data transmission and visualization, and network. In the end of the paper, it is summed up that Web 2.0 is much more advanced compared to Web 1.0 in terms of providing remote laboratory applications to other users.

Julien Broisin, Remi Venant and Philippe Vidal in their work “Lab4CE: a Remote Laboratory for Computer Education” introduce the Lab4CE (Lab for Computer Education) environment, which can be useful for those, who learn aspects of work with computer (for instance, Linux commands, file system organization etc.) [6]. Furthermore, results of the research and statistics are presented, which are important for improving the usability and are a kind of feedback from real students. Additionally, this article answers the question of how virtualization tools can be used in remote laboratories.

Some research findings propose unusual solutions for remote laboratories. A good example of that is “Augmented Reality for the Improvement of Remote Laboratories: An Augmented Remote Laboratory”, authored by Jose Manuel Andújar, Andrés Mejías, and Marco Antonio Márquez. The main idea of the paper is that augmented reality is the intermediary between a user and a remote laboratory, and can be a good solution of implementing user interface because it brings more realism [7]. However, it requires more steps in creation of remote laboratory and experience in the field of augmented reality. As an illustration of capabilities of this proposal, the design of a digital control system based on an FPGA development board is presented.

The problems of remote laboratory design are described in detail in the article “Design and Implementation issues for Modern Remote Laboratories” (Eliane G. Guimaraes, Eleri Cardozo, Daniel H. Moraes and Paulo R. Coelho). The main topics are access control, security and the integration of QoS (Quality of Service) [8]. At the end of one paper, the authors conclude that programming languages such as Java, Python and Matlab seem more appropriate for coding experiments in the engineering domain of a system. Furthermore, it is stated that the most suitable architecture is one containing microserver and is AJAX-based. Lastly, authors highlight importance of using federated operations, which allows experiment and resource sharing. The common mechanism for achieving this is single sign-on authentication with federated authorization.

Based on the review above, we can summarise the following:

- The interest in implementation of remote laboratories in educational institutions grows over the years, which is caused by modern world challenges and availability of remote communication technologies.
- In most cases, user interface of remote laboratories consists of buttons, sliders, charts and other graphic elements, that can be interacted with by a click on mouse button or tapped by a finger. Although this is the commonly used approach, other more advanced user interface elements such as augmented reality are also possible.
- The important points in remote laboratories implementation are security and access control, so that corresponding web application should contain authentication and authorization procedures.
- Feedback from students and statistical information about remote laboratory use can be helpful for improvement of these systems and eliminating drawbacks that worsen user experience.

Isolation of previously unexplored parts of the general problem. Most articles describe technical details of web applications for remote laboratories and do not contain much information on user interface elements, especially in the power electronics domain. There are no articles that provide a comprehensive description and justification of the chosen input/output elements and recommendations for their proper use. Furthermore, user interface design in the context of remote laboratory implementation involves various issues that need to be discovered and resolved.

The research objective is to become familiar with the analysis of potential problems that may arise during the implementation of user interfaces for remote laboratories, and to highlight some practical aspects that may simplify this task, with a focus on remote power electronics laboratories. Moreover, the importance of user experience for user interface design needs to be determined, along with typical elements of web application screens for performing remote experiments in the field of power electronics. These results will help to make the process of user interface implementation easier and more effective.

Presentation of the main material. User interface (UI) is the point of human-machine (computer) interaction and communication with a device. UI includes display screen, appearance of a desktop or web application, menu in Android devices, keyboard, touchpad, touchscreen, mouse, slider and many other elements that can be viewed by eye and at the same time interacted with.

A properly designed user interface encourages an easy, natural, and engaging interaction between a user and a system, and it allows users to carry out their tasks. With a good user interface, the user can forget that he or she is using a computer and get on with what he or she wants to do [9]. However, it is important to note that judging whether a user interface is good or bad can be different and subjective, as each user has their own user experience.

Another important aspect of user interface design is known as user experience. When designing a system, it is better to provide a good and convenient way of interaction that is understandable and clear for most of the potential target audience, so that consumers will give you good feedback on your product. It simply means that user experience recommendations and common practices for user interface implementation should be appreciated.

The Power Electronics remote laboratory, implemented at Chernihiv Polytechnic National University (within the NGI Search project, grant agreement No 101069364), consists of 5 main components: student's computer, router, server, Boost experiment and Buck experiment (see Fig. 1).

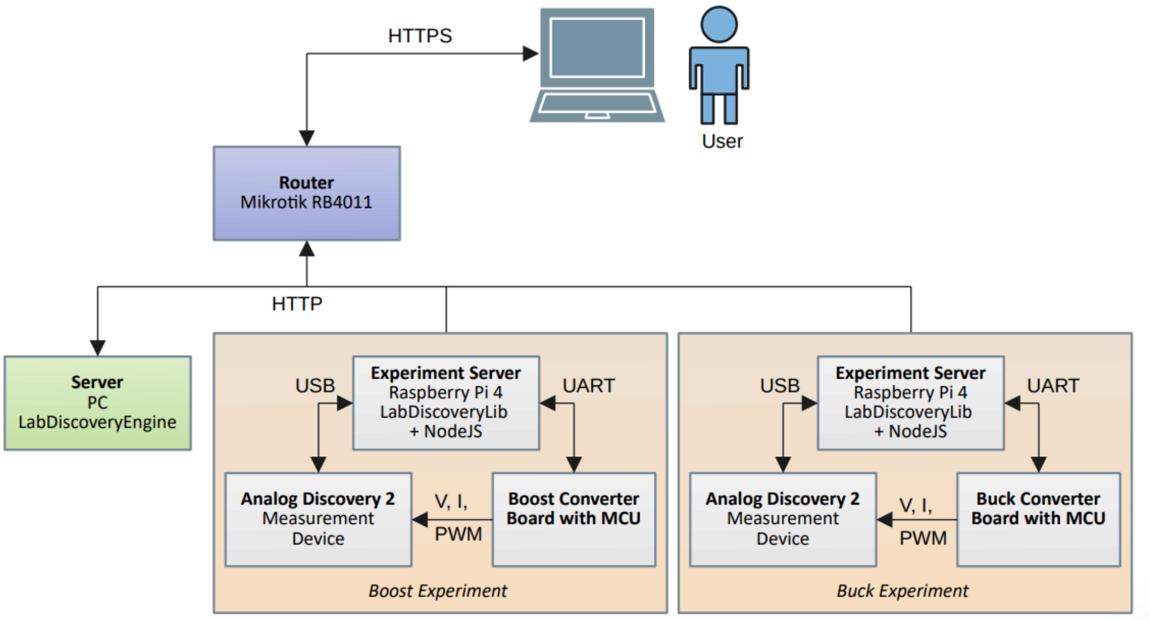

Fig. 1. Power Electronics Remote Laboratory Architecture

Source: developed by the authors.

As it can be seen on the figure above, a user (actually an electronics student) can only access the system via the web application on the local computer. In other words, the access is possible only from the front-end part of the remote laboratory, while all the hardware and back-end server part is hidden from the user.

Router is a network device that transmits requests from the user to the server and retrieves responses containing measurement data and operations to be performed with real hardware.

Server is a desktop computer installed in the real laboratory along with a router and hardware for power electronics experiments. The purpose of this computer is to quickly maintain and monitor the work of the remote laboratory. These tasks can be handed over to the system administrators or to the developers of the server part. Furthermore, this server is responsible for access control and security measures, which is achieved by embedding the LabDiscoveryEngine subsystem.

The Boost and Buck Experiment includes an Experiment Server that performs measurements on demand (actually, in response to the user's request). The Analog Discovery 2 multifunction device allows to retrieve real-time values of Voltage (V), Current (I) and PWM from the Board with MCU. The only difference between the Boost experiment and the Buck experiment is the converter topology and some circuitry.

Talking about the user interface, 2 parts should be highlighted. The first one is for authentication and authorization tasks (Security subsystem), which is mandatory because access to the remote laboratory must be restricted to those who are not students of the educational institution. The second one (Experiment subsystem) is for the web application, where the user interacts with buttons and sliders. This is the first practical aspect of user interface implementation in remote laboratories, which divides the system into the Security subsystem and Experiment subsystem.

Security subsystem based on the LabDiscoveryEngine. Web application containing the experiment can only be accessed if the user has been granted special access to the system.

For the implementing of Security subsystem, it is easier and less time-consuming to integrate solutions that have already been developed, where possible. A good example of such solutions is LabDiscoveryEngine – an open-source remote lab management system that allows institutions to publish, share, discover and access their physical educational laboratories, thus democratizing and increasing access to equipment and resources regardless of space and time and saving costs [10].

Key features of LabDiscoveryEngine subsystem include:

- open source, so that communities can improve this project if they want;
- facilitating the remote creation and maintenance of remote laboratories in various fields of study;
- providing authentication and authorization mechanisms for remote laboratories;
- integration with the LabsLand portal.

When a student wants to access the laboratory, they should use the login and password provided by the course supervisor or lecturer (see Fig. 2).

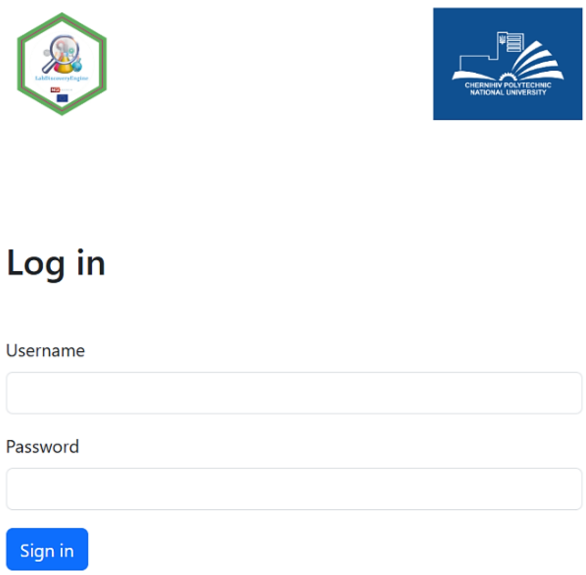

Fig. 2. Log in window to the remote laboratories' environment [10]

If a user successfully enters confidential information, a unique session identifier is issued, allowing any available remote laboratory to be used (see Fig. 3).

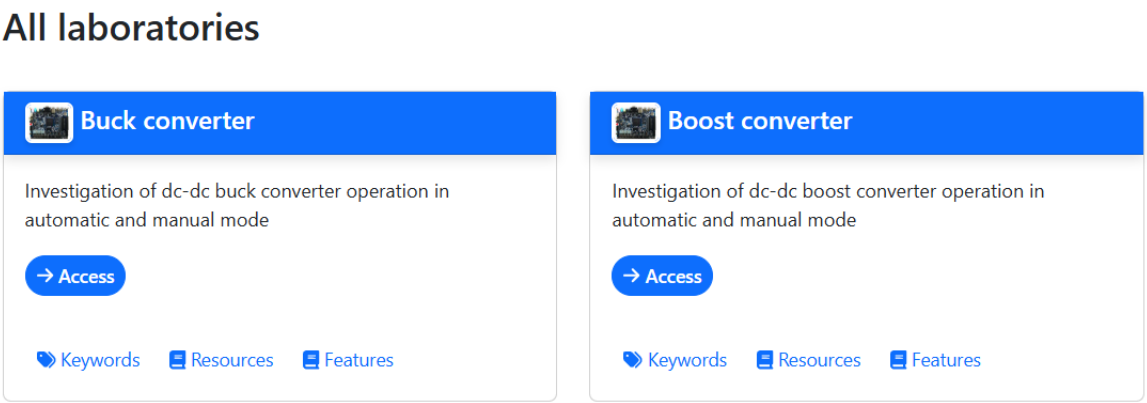

Fig. 3. Available remote laboratories screen [10]

To open a remote laboratory web application, a student must click on the "Access" button. After that, if the lab is not in use at that moment, then the user will be redirected to another page with the Experiment subsystem, otherwise a corresponding message will be displayed that the laboratory is busy. This is another task for the LabDiscoveryEngine to determine whether a laboratory is in use or not.

As a conclusion to this section, we can say that providing security and easy limited access to remote laboratories is easy to implement thanks to available open source solutions such as LabDiscoveryEngine. This is another practical aspect related to the implementing the user interface of remote laboratories.

Experiment subsystem. The Experiment subsystem allows students to perform experiments with DC-DC Buck and Boost Converters. However, only one laboratory is accessible per web-page. It means that after entering, for example, DC-DC Buck Converter from LabDiscoveryEngine, to load DC-DC Boost Converter laboratory you need to back and select another laboratory. This approach can be helpful because students can use different remote laboratories concurrently (i.e., one student works with Boost Experiment, second one performs the Buck experiment at the same time), so that the queue of students ideally becomes twice small.

General view of the Experiment subsystem of power electronics remote laboratory, developed in the project, is presented in Fig. 4.

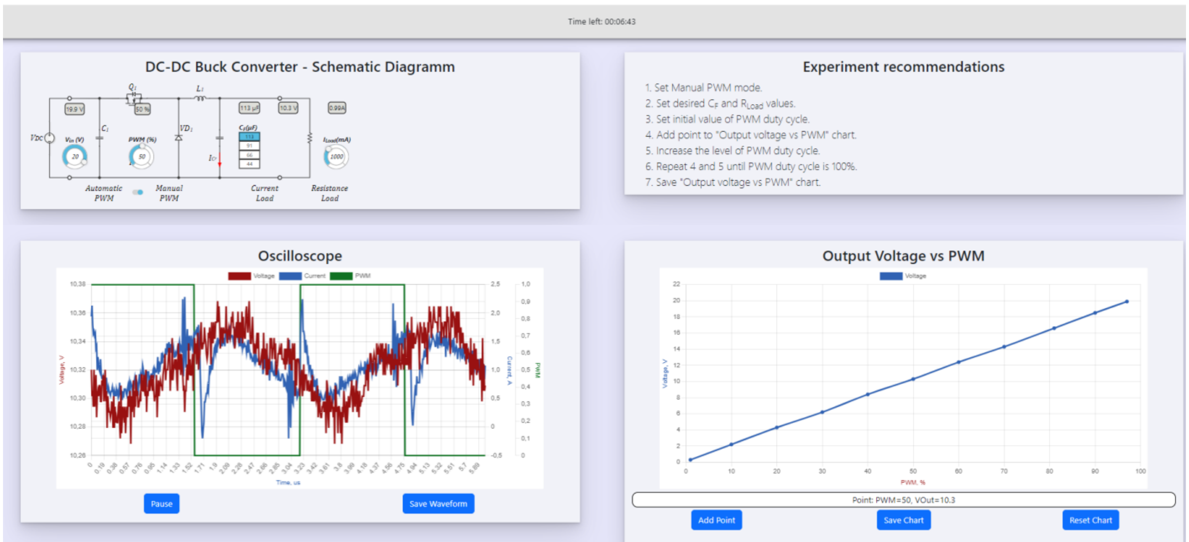

Fig. 4. General view of Experiment subsystem

Source: developed by the authors.

The experiment subsystem window has been designed to provide access from one page to all parts of the experiment, including the measured data and signals, control elements, recommendations, etc. Finally, it was designed consisting of 4 panels:

- Schematic diagram (DC-DC Buck Converter or DC-DC Boost Converter);
- Experiment recommendations;
- Oscilloscope;
- Output Voltage vs PWM.

As previously stated, queuing and scheduling of access is a key issue in remote laboratory development. To enhance user experience and minimise the time spent waiting for experiment equipment to become available, a countdown timer has been incorporated into the interface at the top of the window. This timer provides an additional solution to the problem of long queues by ensuring a balanced allocation of time for the experiment. Based on assessments (academic staff of the university, lecturers of "Power electronics" course in CPNU), the optimal time for executing all experiments has been determined to be 10 minutes, which is sufficient for completing all tasks without causing long student queues.

In terms of implementing user interfaces in remote laboratories, it is recommended that single-page front-end frameworks such as React, Angular, Vue.js or any other relevant ones are utilised. By consolidating all elements of the user interface on a single page of the web application, students are able to perform experiments more efficiently, as they do not need to refresh, navigate to the next or previous page, which can be time-consuming. However, if the number of elements is very high, the user may need to scroll down the page constantly, which can be inconvenient. In such cases, it would be beneficial to enable/disable components dynamically to enhance the user experience.

Following a thorough comparison of the available options, Vue.js was selected for use in the project. This framework is characterised by its approachability, performance and versatility in building user interfaces [11]. It utilises an MVVM pattern (model-view-viewmodel), which facilitates the development of programming code and the testing of individual modules. Additional features of Vue.js include a component-based structure, reactivity, more advanced transitions and routing. Furthermore, the Bootstrap framework allows panes of the remote laboratory to be placed as a table with dynamic size change when the screen becomes smaller [12].

Following the completion of the general user interface for the power electronics remote laboratory, features of individual components of the Experiment subsystem, with a focus on enhancing the user experience, should be discussed.

Figure 5 demonstrates the user interface of *the Schematic Diagram* for DC-DC Buck Converter.

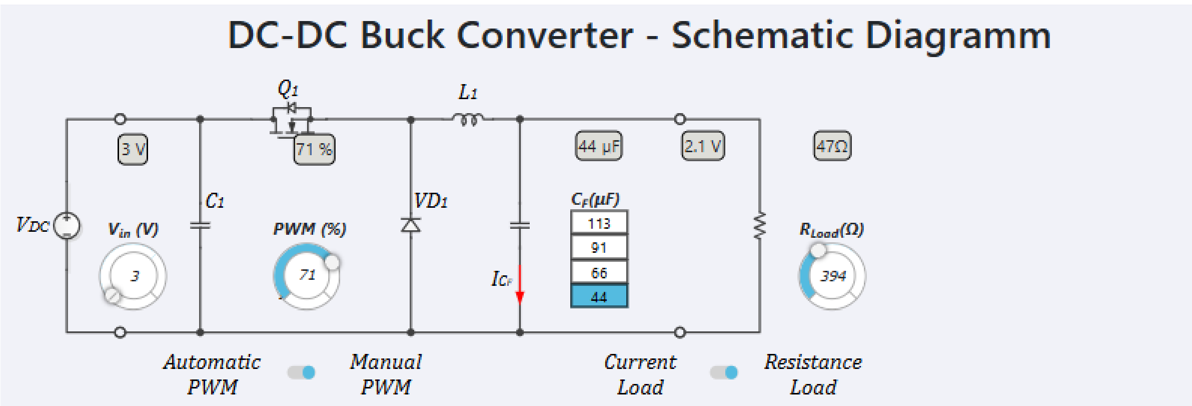

Fig. 5. View of Schematic Diagram with control elements and sensor indicators

Source: developed by the authors.

It should be noted that the Schematic Diagram pane fulfils two functions: firstly, it provides a visual representation of the circuit under investigation by the student in the experiment; secondly, it incorporates control elements and sensor indicators into the schematic diagram, where they interact with the elements of the circuits. From a didactic perspective, this feature is advantageous as it enables students to associate interface elements with their role in circuitry. For instance, the input voltage slider, located on the left side of the image of the input voltage source, serves as an interactive component. Additionally, the schematic diagram is presented in a manner consistent with the format found in educational materials such as books or lecture notes, further enhancing the student's learning experience. From a technical perspective, the web application utilised an SVG file of the electric circuit due to the vector format's ability to maintain quality when scaled. This file format is particularly well-suited for web applications operating on devices with varying screen resolutions. On top of the transparent image, real value indicators and control elements are positioned. To ensure the correct placement of all these elements within the gaps of the electric circuit, additional CSS styling was incorporated, involving manipulations with relative and absolute positions. The implementation of a grey background for the real-value indicators serves to prevent students from erroneously using them as input elements.

In order to optimise the user experience, the input element type should be compatible with the type of value, list or range, etc. For instance, in our case, in the remote laboratory, one filter capacitor value out of four available should be selected. As a solution, the 4-mode switch was used, which also perfectly fits the screen. However, it is important to note that the input voltage should be varied within the range of 3 to 21 V. To facilitate precise value entry, a round slider storing 18 possible values is recommended. Students can enter a more precise value by clicking in the centre of the slider [13].

Vue.js reactivity allows to dynamically control the visibility of elements, enhancing the user experience in remote laboratories. For instance, when the mode selector is set to "Manual PWM", a dedicated round slider becomes accessible for entering PWM mode. In the other position of the selector, the slider is concealed.

The "Experiment recommendations" pane looks clear. It is only a set of steps which the student needs to reproduce to complete the task (see Fig. 6).

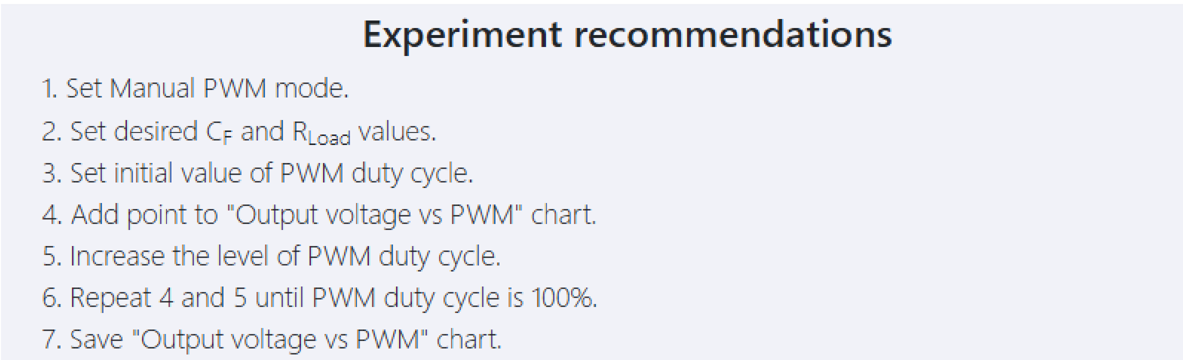

Fig. 6. View of Experiment recommendations

Source: developed by the authors.

The next part of the remote laboratory interface, pane "Oscilloscope", shows oscillograms (visualizations of signals over time) of voltage, current and PWM values (Fig. 7).For the visualisation of datasets as a chart, the previously implemented library was used [14].Two buttons below the chart are used for controlling the oscillograms. The first button, labelled 'Start/Pause', enables the user to control the oscillograms by selecting whether values are to be read from the oscilloscope or not. The second button, 'Save Waveform', allows students to capture a screenshot of the chart and save it on their computer.

This small button enhances the user experience by eliminating the need for manual screenshot capture and component trimming in laboratory work reports. It is also important to note that the oscilloscope is fully automated, eliminating the need for manual control adjustments (time/div, V/div and A/div) for the simplicity and better user experience.

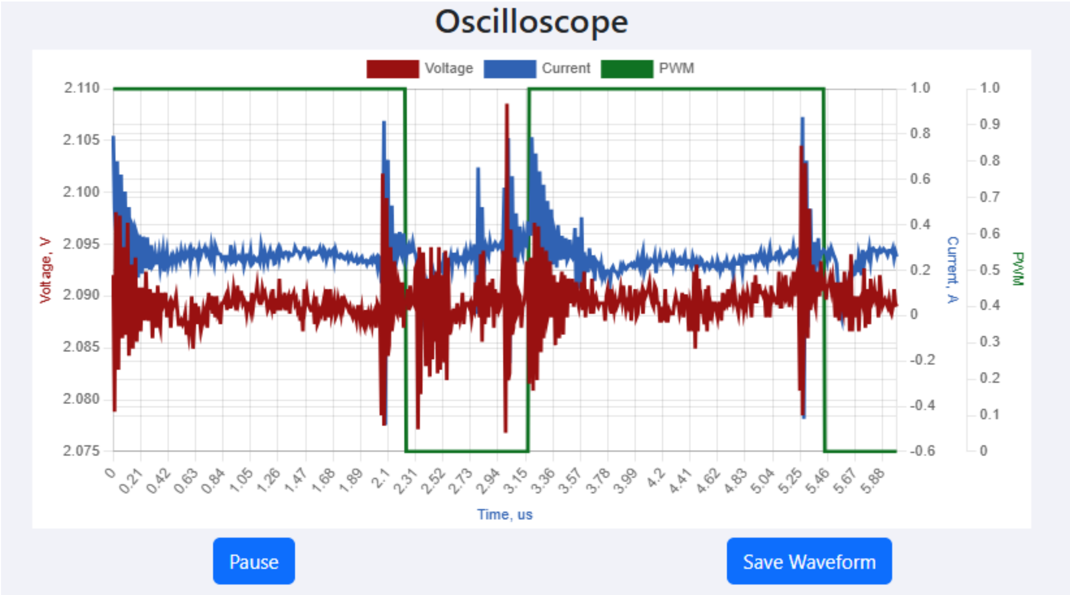

Fig. 7. View of Oscilloscope

Source: developed by the authors.

The final component of the web application is the chart pane labelled 'Output Voltage vs. PWM'. This section of the remote laboratory interface is designed to create a graphical dependency (chart) between output voltage in a circuit and PWM value in manual mode (Fig. 8).

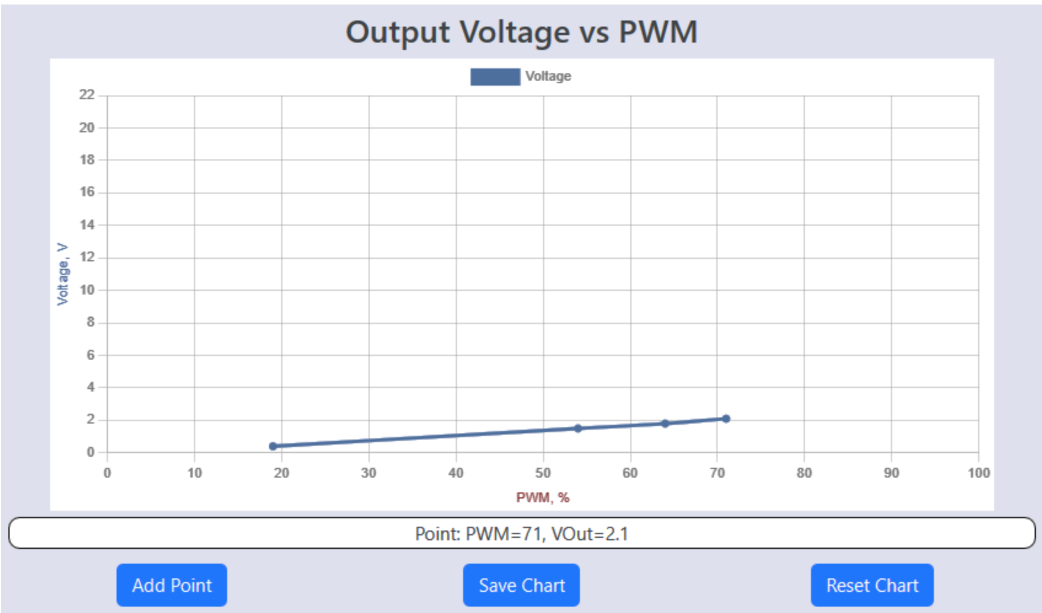

Fig. 8. View of Output Voltage vs PWM

Source: developed by the authors.

This part is used in conjunction with the control elements on the Schematic diagram of the converter. When the student sets the manual mode and selects some of PWM's duty cycle for the MOSFET switch, one point on the chart can be added by pressing the "Add Point" button below the chart. The information about the duty cycle and corresponding output voltage to be added is also displayed under the chart. The student then needs to repeat the procedure iteratively for other duty cycle values to complete the chart for values from 0% to 100%. Two additional buttons are also provided for ease of use: to save the chart as a PNG file (Save Chart button) and to clear the chart of all existing points (Reset Chart button).

Another important aspect when implementing user interfaces is that they should be simple and not overcomplicated with different buttons, elements, etc. Furthermore, colors and fonts should be high contrast for better readability.

As a result, we have demonstrated the most important practical aspects for creating a remote laboratory user interface with security procedures based on the solution implemented in CPNU. Approaches for improving the user interface and user experience, used for the power electronics remote laboratory, can also be used for other remote laboratories. In the future, this remote laboratory web application can be improved by collecting statistics on students' usage for a better user experience.

Conclusions. Considering the large number of scientific literature on the subject, the issue of remote laboratory development is of considerable significance in the contemporary world. A thorough analysis of related studies has enabled the identification of the primary challenges that may emerge during the implementation of remote laboratories, including security, system performance, user interface, and optimisation. This study explores the potential of remote laboratories as a means for students to engage with the practical components of academic disciplines, with a particular focus on security and user interface/user experience considerations. The paper presents the practical aspects of remote power electronics laboratories, as implemented at Chernihiv Polytechnic National University, including the division of the system into an Experiment subsystem and a Security subsystem, both of which are controlled by the remote laboratory management system LabDiscoveryEngine. This approach enhances the security of remote laboratories. Several key approaches for improving the user experience were discussed and implemented, such as regulating queues through LabDiscoveryEngine functions and experiment timer in the web application, as well as the use of a single-page framework to create appropriate web applications. The use of appropriate input forms, as well as sensor indicators and their relative position on the schematic diagram of the experiment, was also considered a key element of the didactic approach, as well as user experience.

Finally, the user interface of the power electronics remote laboratory was presented and implemented on the experiment server based on Vue.js and Bootstrap, utilising all the aforementioned approaches for the enhancement of user experience for two experiments (buck and boost DC-DC converters). The findings of the research can also be applied to other human-machine interface implementations, extending beyond remote laboratories and academia, such as industrial automation systems. The next stage of development will be to collect statistics on student usage to further enhance the user experience of the remote laboratory web application. The proposed approaches will also be translated to other remote laboratories, such as microcontroller and FPGA systems, which are currently in development.

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ПРАКТИЧНІ АСПЕКТИ СТВОРЕННЯ ІНТЕРФЕЙСУ КОРИСТУВАЧА ВІДДАЛЕНОЇ ЛАБОРАТОРІЇ ЕЛЕКТРОНІКИ

Розвиток світу інформаційних технологій дає можливість віддалено вирішувати велику кількість задач: замовляти їжу, читати книги, насолоджуватися творами мистецтва. Це ж саме стосується і навчального процесу. Для вивчення практичної частини різних дисциплін, у тому числі силової електроніки, коли аудиторні заняття неможливі або становлять ризик, у пригоді стають віддалені лабораторії. Вони допомагають здобувачам освіти, які живуть у місцях масового поширення хвороб та військових конфліктів, адже для навчання в цьому випадку потрібні лише пристрої з доступом до Інтернету та сам стабільний Інтернет.

Однак завжди актуальною є проблема якості та корисності таких технологій, яка багато в чому залежить від реалізованого інтерфейсу користувача. Саме тому велику увагу при розробці слід приділяти інтерфейсу користувача віддалених лабораторій, у тому числі пов’язаних із силовою електронікою. Детальне дослідження цієї теми забезпечить краще врахування досвіду використання та кращі відгуки від студентів. Крім того, це спростить процес майбутнього впровадження віддалених лабораторій.

Актуальні дослідження щодо впровадження віддалених лабораторій показали, що мало уваги приділяється конкретним елементам інтерфейсу користувача, які використовуються у відповідних системах, та обґрунтуванню вибору елементів.

Метою цієї статті є висвітлення проблем, які можуть виникнути під час впровадження інтерфейсу користувача віддалених лабораторій силової електроніки, та запропонування практичних аспектів його спрощення на основі реальної системи.

За результатами проведених досліджень запропоновано декомпозицію інтерфейсу користувача на фронтенд-підсистеми з використанням односторінкових вебзастосунків для клієнтської частини. Дано пояснення елементів для розмітки сторінки дистанційної лабораторії силової електроніки та зовнішнього вигляду сторінки, включаючи різні панелі, графіки, кнопки, перемикачі тощо.

У цій роботі на реальному прикладі продемонстровано загальний підхід до створення інтерфейсу користувача віддаленої лабораторії силової електроніки. Наведено проблеми, які можуть виникнути. Представлені матеріали можуть бути використані для більш спрощення розробки майбутніх систем віддалених лабораторій.

Ключові слова: *віддалена лабораторія; інтерфейс користувача; силова електроніка; вебзастосунок; фреймворк Vue.js; front-end.*

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