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Enhancing Engineering Education: Integrating Remote Laboratories in Power Electronics Courses

Mejora de la enseñanza de la ingeniería: Integración de laboratorios remotos en los cursos de electrónica de potencia

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Abstract- This research paper explores the integration of remote laboratories and Project-Based Learning methodologies in the teaching of power electronics within engineering education. The study focuses on the implementation of a modular power transmission system project for electric vehicles, enabling students to apply theoretical knowledge to practical scenarios. By providing remote access to physical laboratory equipment, this approach addresses challenges related to equipment availability and scheduling, offering flexibility and enhancing student engagement.

Keywords: Remote Laboratories, Project-Based Learning (PBL) and Power Electronics Education.

Resumen- Este trabajo de investigación explora la integración de laboratorios remotos y metodologías de Aprendizaje Basado en Proyectos en la enseñanza de la electrónica de potencia dentro de la educación en ingeniería. El estudio se centra en la realización de un proyecto de sistema modular de transmisión de potencia para vehículos eléctricos, que permite a los estudiantes aplicar los conocimientos teóricos a escenarios prácticos. Al proporcionar acceso remoto a los equipos físicos de laboratorio, el enfoque aborda los retos relacionados con la disponibilidad de equipos y la programación, ofreciendo flexibilidad y mejorando el compromiso de los estudiantes.

Palabras clave: Laboratorios remotos, aprendizaje basado en proyectos (ABP) y enseñanza de la electrónica de potencia.

1. INTRODUCTION

Information and Communication Technologies (ICTs) encompass a diverse range of digital tools and systems designed to facilitate the acquisition, processing, storage, transmission, and presentation of information in multiple formats, including text, audio, images, and data. The widespread adoption of ICTs has meaningfully impacted various aspects of daily life, particularly in education, where they have reshaped teaching methodologies and enabled new learning experiences, such as remote laboratories (Ávila Díaz, 2013).

Remote laboratories involve real physical experiments where responses are influenced by factors such as environmental conditions, measurement uncertainties, and equipment variability. This integration of ICTs allows remote laboratories to provide 24/7 accessibility, enhanced security, and reduced maintenance, making them a valuable tool for modern education. However, they also face challenges related to reliability, adaptability to student needs, and user engagement (García-Zubía, 2021).

Remote laboratories can be classified into real-time laboratories, where users directly interact with experiments, such as robotics applications (Angulo et al., 2017), and ultraconcurrent laboratories, which use pre-recorded data to provide immediate feedback while maintaining measurement variability (Arguedas-Matarrita et al., 2022). Both approaches employ ICT infrastructure to optimize accessibility, ensuring that students can conduct meaningful experiments without the constraints of physical presence or scheduling limitations.

Project-Based Learning (PBL) is an educational methodology in which the students organize themselves to tackle a specific *final product* (e.g., a robot design, a scientific paper, an online chatting tool, an artistic creation, etc.). This approach implies the acquisition of skills such as coordination, negotiation, or critical thinking, not common in traditional frameworks. Moreover, each student will work on tasks more appealing to them, improving the final product and, in the end, the learning outcomes. It also enables the knowledge exchange between the involved students, establishing a collaborative learning context (Perrenoud, 2000). This learning framework has been effectively implemented at the university education level to teach image processing, or 3D technology, for example (Cabrera - Peña et al., 2021). Currently, knowledge is available and free on the Internet, and tools like ChatGPT has boosted its management and understanding. PBL could leverage this context enhancing the skill-organized learning.

Thus, this work aims to design a learning scenario that combines ultraconcurrent remote laboratories with the PBL methodology in order to actively engage students during their knowledge acquisition phase, overcoming the potential limitations associated with laboratories accessibility, and bringing students closer to solve a real-world problem.

2. CONTEXT

In recent years, educational institutions worldwide have been exploring innovative approaches to improve student engagement and learning outcomes. One approach is the integration of remote laboratories into engineering education. This shift is particularly significant in fields such as industrial electronics and power systems, where hands-on experimentation and real-world applications are critical to deepening theoretical understanding. Remote laboratories have emerged as a feasible solution to overcome the limitations of traditional physical laboratories, particularly in terms of accessibility, flexibility and scalability (Van den Beemt et al., 2023).

The University of Las Palmas de Gran Canaria (ULPGC), through the Educational Innovation Group in Design and Implementation of Integrated Systems, has pioneered the use of remote laboratories in the educational context. The project entitled "Development of Remote Laboratories for the School of Industrial and Civil Engineering (EIIC)" is designed to integrate remote access to physical laboratory equipment into the engineering curriculum, aiming to address the challenges associated with traditional in-person laboratory sessions.

This project focuses specifically on the subject of Power Electronics, which is taught in the first semester of the fourth year of the Bachelor's Degree in Industrial Electronics and Automation. This subjects usually requires students to work with complex and expensive equipment such as DC power supplies, oscilloscopes and motors. However, scheduling, equipment availability, and physical laboratory space constraints can limit students' ability to engage with these tools, especially in large cohort settings. (Haque et al., 2015).

The introduction of remote laboratories offers a solution to these challenges by allowing students to interact with real hardware remotely, conducting experiments and learning practical skills without the geographical or temporal restrictions of physical laboratory sessions. This setup provides students with the flexibility to experiment at their own pace, reinforcing the theoretical knowledge gained in lectures while addressing the need for hands-on learning in a modern engineering curriculum. In this line, recent studies have found that remote labs significantly improve students' practical skills and engagement in subjects like power electronics (López Gutiérrez et al., 2021).

Moreover, the integration of PBL within the Power Electronics course serves as the foundation of the learning methodology. PBL, as previously explained, is an educational approach where students tackle real-world engineering problems, and it has been widely recognized for its ability to promote deeper learning and critical thinking. In this context, students should develop a modular power transmission system for an electric vehicle, a project that integrates various power electronics concepts. Over the duration of the course, students progressively engage with different stages of the project, from configuring power supplies to controlling motors, applying their theoretical knowledge in a hands-on setting (Lavado-Anguera et al., 2024).

This project represents a significant step towards modernizing engineering education, providing students with the flexibility, resources, and learning methodologies that will potentially enhance their academic and professional careers. Through the integration of remote laboratories and PBL, this approach aims to bridge the gap between theoretical knowledge and practical experience, preparing students for the challenges of the future in a realistic scenario.

3. COURSE DESCRIPTION

A. Mechanical & Electronic Components

As summarized in Figure 1, the design of a remote laboratory involves the integration of various technologies. In this case, the remote laboratory requires a robust physical structure and a mechanical system that provides movement in the three axes. Interface enables real-time visualization from fixed webcams positioned to offer a clear view of the experiment. Additionally, the prototype incorporates an electronic control system that, through sensors and actuators, automates the laboratory's functionalities, ensuring the remote and secure execution of the experiments.

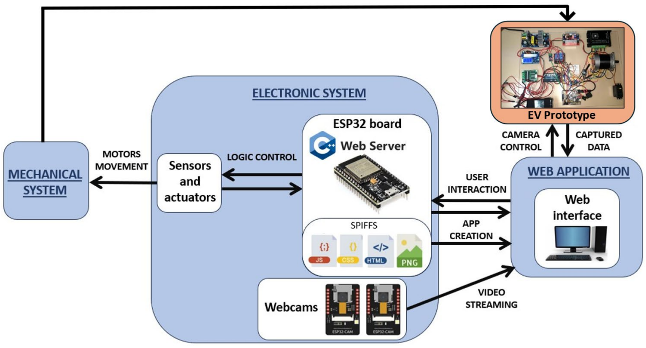

Figure 1: Diagram of the mechanical and electronic connection

B. Web interface

The web application interface (Figure 2) allows users to select a camera and view its live feed via internal link. On the left, there is a camera selector, an information panel and an event log. In addition, a parameter selector enables users to choose different configurations based on the electric car experiment being conducted. If no camera is selected when entering the application, an error message is prompted. The cameras are strategically placed to provide a clear view of the area of interest. The event log displays real-time updates on the status of the feed and selected parameters. The interface controls are intuitive, allowing users to switch between cameras and adjust experiment parameters without interruption. During use, buttons are temporarily disabled if a connection problem occurs to prevent errors.

Figure 2: Web application interface

C. *Final Integration*

With the integration of the previous part, the remote laboratory prototype is completed. The electronic system controls the mechanical system for camera positioning that is shown in the user's web application. This allows for remote control with real-time image and data transmission. Figure 3 presents the final setup of the remote laboratory, showing both the physical components and the web interface displaying the live feed.

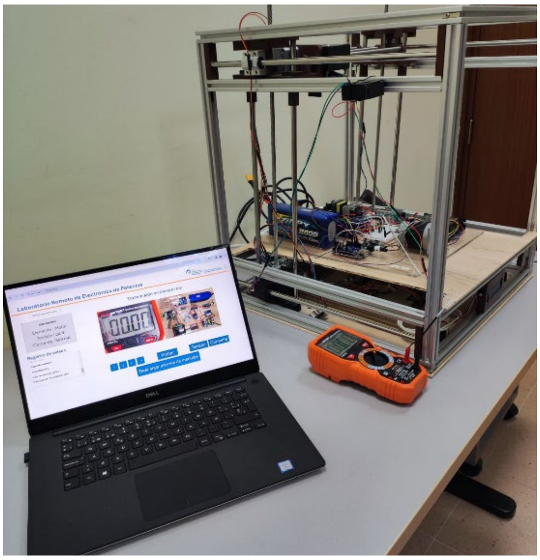

Figure 3: Final setup

4. RESULTS

The development of the remote laboratory has been structured to provide an interactive and scalable learning environment for students studying power electronics in electric vehicles. This learning scenario has been designed using a PBL approach, where students collaboratively work on a real-world challenge: developing and optimizing a remote-controlled power system for an electric vehicle (EV). Through the remote laboratory, students define problems, design solutions, experiment, and iteratively improve their implementations, integrating knowledge from power electronics, automation, and embedded systems.

The project has been structured into five interconnected phases, as depicted in Figure 4, each aligning with a specific engineering task that contributes to the final goal: controlling an EV power system remotely.

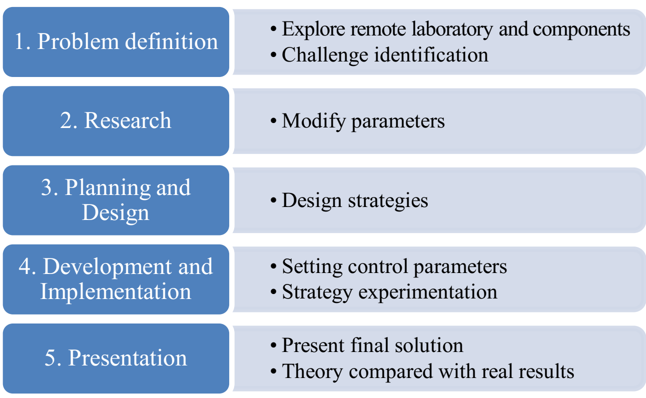

Figure 4: Stages of Project-Based Learning

1. Students are introduced to the real-world problem of managing power electronics in an EV. They access the remote laboratory's web interface to observe the system in real time, identify key components (i.e., battery management system, DC-DC converters, motor, sensors), and explore existing documentation. Through guided discussions, they should define the project's objectives and constraints, such as ensuring battery safety, efficient power conversion, and precise motor control.
2. Students investigate the role of PWM and the SV input in BLDC motor control. They analyze videos of incorrect and correct experiments, understanding how PWM resolution affects output voltage and motor efficiency.
3. Based on their research, they design strategies to prevent system failures. They define safe input parameters and develop a verification protocol to ensure that the speed controller is correctly configured.
4. They implement their solution by adjusting charge values in the BMS and monitoring the system's response. During discharge, they maximize motor speed and analyze the voltage evolution of each cell, ensuring it remains within safe limits.
5. Students present their findings, comparing real measurements with theoretical predictions, and proposing improvements for energy efficiency and system safety in the EV power system.

The remote laboratory has been designed to function through pre-recorded scenarios, allowing students to engage with real-world power electronics concepts in a controlled and progressive manner. The students can interact with different operational scenarios, modifying system parameters, and analyzing the effects of their decisions on the experiment. This setup enables self-guided exploration and fosters a deeper understanding of system behavior, even in a remote setting. Table 1 summarizes the practices performed, the parameters adjusted, and the observations recorded from the corresponding videos.

5. CONCLUSIONS

The remote laboratory offers various advantages in the educational context. It facilitates error identification in system configuration without the risk of damaging hardware, encourages learning through trial and error, and allows students to refine their hypotheses based on real system behavior. Additionally, it strengthens the connection between theory and practice by comparing theoretical models with experimental data. Its accessibility, enabling students to participate from various locations without the need for physical presence in the lab, broadens learning opportunities.

Although the laboratory has not yet been deployed in a formal course, its design aligns with educational, ensuring active learning and conceptual understanding. In the future, surveys will be implemented to assess student satisfaction with the remote laboratory experience. These surveys will gather valuable feedback regarding the usability of the platform, the perceived effectiveness of the learning process, and the overall learning experience. By collecting students' perspectives on key aspects such as engagement, clarity of instructions, and the

Table 1: Relationship between modified parameters, videos, and observations in the remote laboratory. SV: Space Vector; PWM: Pulse Width Modulation; DC: Direct Current

<table>
<tr><th>Practice</th><th>Video</th><th>Modified Parameter</th><th>Observations on the Vehicle</th><th>Oscilloscope Measurement</th></tr>
<tr><td rowspan="2">1</td><td>Video 1 (Incorrect)</td><td>Power OFF</td><td>Motor does not rotate</td><td>No voltage detected</td></tr>
<tr><td>Video 2 (Correct)</td><td>Power ON</td><td>Motor vibrates but does not rotate</td><td>Ripple voltage detected, no DC component</td></tr>
<tr><td rowspan="3">2</td><td>Video 1 (Incorrect)</td><td>Variable voltage at SV input</td><td>Motor rotates depending on applied PWM voltage</td><td>Pulse train duty cycle compared with phase voltage</td></tr>
<tr><td>Video 2 (Incorrect)</td><td>75% duty cycle but incorrect PWM configuration</td><td>Motor fails to reach expected 75% voltage</td><td>Voltage deviation due to insufficient resolution</td></tr>
<tr><td>Video 3 (Correct)</td><td>75% duty cycle but correct PWM configuration</td><td>Motor achieves expected 75% voltage</td><td>Exact relation between duty cycle and phase voltage</td></tr>
<tr><td rowspan="2">3</td><td>Video 1 (Incorrect)</td><td>Inadequate voltage</td><td>Red LED (malfunction)</td><td></td></tr>
<tr><td>Video 2 (Correct)</td><td>System reset</td><td>Green LED, system ready</td><td></td></tr>
<tr><td rowspan="2">4</td><td>Video 1 (Verification)</td><td>Power supply output</td><td></td><td>24V output observed.</td></tr>
<tr><td>Video 2 (Correct)</td><td>Buck-Boost converter output voltage</td><td></td><td>Fully charged voltage (number of cells × 4.2V)</td></tr>
<tr><td rowspan="2">5</td><td>Video 1 (Correct)</td><td>Boost input voltage</td><td>Charge-discharge relay activates</td><td>Constant 28V output voltage maintained</td></tr>
<tr><td>Video 2 (Correct)</td><td>Individual cell voltages</td><td>Speed increased to maximize discharge rate</td><td>Continuous cell voltage monitoring</td></tr>
</table>

integration of theory and practice, these surveys will provide insights into areas for improvement of this approach. Ultimately, finer adjustments will potentially enhance the educational experience, maximizing the benefits of this innovative teaching tool.

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