OUTLOOK OF A WEB-BASED OSCILLOSCOPE CLONE FOR E-LEARNING

VISÃO GERAL DE UMA APLICAÇÃO WEB PARA SIMULAÇÃO DE UM OSCILOSCÓPIO REAL

VISIÓN GENERAL DE UNA APLICACIÓN WEB PARA SIMULAR UN OSCILOSCOPIO REAL

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Abstract

This paper overviews the software architecture, implementation, applications, and preliminary user experience of a computer application that mimics an Oscilloscope and a Signal Generator, in the context of a course on fundamentals of electrical circuit analysis (TCIRC, ECE degree @ ISEP). This web app (available at http://osciloscopio.dee.isep.ipp.pt/) can operate in *Simulation mode* or *Acquisition & Control mode*, namely for: i) students to e-learn the basic operation and functionality of an Oscilloscope and Signal Generator and prepare for the lab class & test; ii) live in-class teaching & demos iii) producing waveforms for slides, exercise books, lab scripts and exams; iv) capturing real circuit signals, for further analysis and processing; v) remote experimentation, to complement or replace *in-loco* work. This tool has been used by over 200 students under the TCIRC course, firstly for off-class preparation of a lab script on the basic operation of the Oscilloscope and Signal Generator, and a couple of weeks later to train for their first lab test. Overall, their "user experience" has been quite positive, as we have inferred from almost two hundred answers to a questionnaire.

Keywords: e-learning, oscilloscope simulator, remote labs, web application, Node.js, JavaScript, user interface, user experience, electrical circuits, signal generator, Moodle tests, online experiments.

Resumo

Este artigo dá uma perspetiva geral sobre uma aplicação *web* que permite simular um Osciloscópio real, resumindo a sua arquitetura e aspetos de implementação de software, bem como a sua utilização por parte de mais de duzentos estudantes da LEEC/ISEP. Esta aplicação *web*, disponível em http://osciloscopio.dee.isep.ipp.pt/, pode funcionar em modo de Simulação ou em modo de Aquisição & Controlo remoto, servindo para: i) autoaprendizagem do funcionamento do Osciloscópio e do Gerador de Sinais; ii) demonstração prática em contexto de aula; iii) produzir formas de onda para diapositivos, cadernos de exercícios ou provas de avaliação; iv) aquisição de sinais reais, para posterior processamento, análise e documentação; v) experimentação remota, complementando (ou substituindo) o trabalho prático em laboratório. Esta ferramenta foi já usada por mais de 200 estudantes da UC de TCIRC para preparar o Guião 2 e a primeira prova laboratorial. Globalmente, a experiência dos estudantes foi muito positiva, segundo as quase duzentas respostas a um questionário.

Palavras-chave: Simulador, Osciloscópio, Gerador de Sinais, aplicação *web*, *online*, autoaprendizagem, ensino à distância, experimentação remota, experiência de utilizador, interface de utilizador, circuitos elétricos, testes *Moodle*, Node.js, *JavaScript*.

Resumen

Este artículo describe la arquitectura del software, la implementación, las aplicaciones y la experiencia preliminar del usuario de una aplicación informática que imita un osciloscopio y un generador de señales, en el contexto de un curso sobre fundamentos del análisis de circuitos eléctricos (TCIRC, grado de ECE @ ISEP). Esta aplicación *web* (disponible en http://osciloscopio.dee.isep.ipp.pt/) puede funcionar en modo de simulación o en modo de adquisición y control, es decir, para: i) que los estudiantes aprendan en línea el funcionamiento y la funcionalidad básicos de un osciloscopio y un generador de señales y se preparen para la clase de laboratorio y el examen; ii) la enseñanza y las demostraciones en directo en clase; iii) la producción de formas de onda para diapositivas, cuadernos de ejercicios, guiones de laboratorio y exámenes; iv) la captura de señales de circuitos reales, para su posterior análisis y procesamiento; v) la experimentación a distancia, para complementar o sustituir el trabajo en el aula. Esta herramienta ha sido utilizada por más de 200 estudiantes del curso TCIRC, en primer lugar, para la preparación fuera de clase de un guión de laboratorio sobre el funcionamiento básico del osciloscopio y el generador de señales, y un par de semanas más tarde para entrenarse para su primer examen de laboratorio. En general, su «experiencia de usuario» ha sido bastante positiva, como hemos deducido de casi doscientas respuestas a un cuestionario.

Palabras-clave: *e-learning*, simulador de osciloscopio, laboratorios remotos, aplicación *web*, *Node.js*, *JavaScript*, interfaz de usuario, experiencia de usuario, circuitos eléctricos, generador de señales, pruebas *Moodle*, experimentos en línea.

1 INTRODUCTION

1.1 Context and motivation

The three last co-authors of this paper have long been involved in the conception of innovative teaching/learning methodologies and tools for courses on DC/AC circuits, such as TCIRC (*Teoria dos Circuitos*), which fits in the 2nd semester of the 1st curricular year of the *Electrical and Computer Engineering* degree at ISEP, addressing AC (linear) circuit and L/C transient analysis (Sousa et al., 2021), (Sousa et al., 2021), (Oliveira et al., 2013), (Macedo et al., 2021), (Oliveira et al., n.d.).

One of these efforts has been on Oscilloscope simulators, which have already proved to be very useful for both students and teachers (as in application domains i) to iii) in the *Abstract*). Previous (stand-alone) versions of this simulation tool have been available and consistently used for almost two decades (Salgueiro, 2005), (Pereira, 2015). This new version (introduced in this paper), designed as a web application, spans its use to a wider dominion and features unprecedented levels of robustness and functionality (as enumerated in the *Abstract*). To our best knowledge, there is no similar web tool available to date, featuring such a realistic and user-friendly interface, operation modes and functionality (Examples of Online Simulators, n.d.).

1.2 Contributions

The work summarized in this paper embeds the following contributions:

- **Design and Implementation of an *Oscilloscope Interface* web app, freely available as open source**: Our primary contribution lies in the design and development of an *Oscilloscope Interface* app which supports two operational modes: *Simulation mode* and *Acquisition & Control mode*. The proposed app "clones" the actual equipment available in the lab, both in user interface and functionality. Importantly, the *app* and the source code are freely available to the international community.
- **Practical utilization and user experience**: The *Simulation mode* has already been used by TCIRC teachers/students for in-class lecturing, preparing Lab Script 2 (on the basic operation of the Oscilloscope and Signal Generator) and the first lab test. A questionnaire to infer about the users' experience resulted in constructive and mostly positive feedback from almost two hundred students.

A couple of our former students have been enrolled in academic projects on oscilloscope simulators. Pedro Salgueiro (Salgueiro, 2005) developed an analogue oscilloscope simulator, while João Pereira (Pereira, 2015) developed a sampling (aka "digital") oscilloscope simulator, like the one reported in this paper. Both previous applications served as benchmarks for this new *Oscilloscope Interface* app. Despite differences in interface and development environment, they share similar operational principles. Salgueiro's "analogue" Oscilloscope simulator featured quite realistic trigger and X-Y modes and a useful signal input via Excel file, while Pereira's "digital" Oscilloscope simulator had an user interface graphically very close to the one of the new web app (same Oscilloscope front panel), but poorer command interactions and signal generator.

Our project builds on these two seminal experiences by solving some of their problems and limitations (e.g. menu functionality, cursor precision, and signal generator capabilities) and growing to a more flexible and proficient software (web) architecture. Evidently, there are still aspects to be improved and functionality to be implemented, which had been previously identified by us and later pointed out by the students (and summarized in Section 3.2).

1.3 Paper organization

The remainder of the paper outlines the most relevant application and software design aspects (Section 2), the application user interface & user experience (Section 3), two case studies on the practical use of the *Oscilloscope Simulator* in the context of the TCIRC course (Section 4) and some concluding remarks (Section 5).

2 APPLICATION & SOFTWARE DESIGN

2.1 Initial application requirements

A set of initial requirements and functionality have been paramount to pave the way for the architectural design and software implementation of the *Oscilloscope Interface* web app, e.g.:

- **Online Accessibility**: online and browser/OS-agnostic access for ease, wide and open use;
- **Realistic user interface**: the Oscilloscope and Signal Generator should mimic the real equipment;
- **Functionality and Modularity**: basic functionality of the Oscilloscope & Signal Generator and a modular software architecture (to facilitate future extensions);
- **Acquisition and Control mode**: the *Server* should communicate with the real Oscilloscope, enabling the *Client* to remotely control the Oscilloscope and to acquire real signal/waveform data;
- **CSV file input**: to define any type of input signal/waveform (time and amplitude data);
- **Data storage**: for saving waveforms/screens as CSV and PNG files, for further use/analysis.

The current version of the app matches the initial requirements and supports several additional features and enhancements, such the "Support" menu and the generation of CSV signals without any restrictions on the number of

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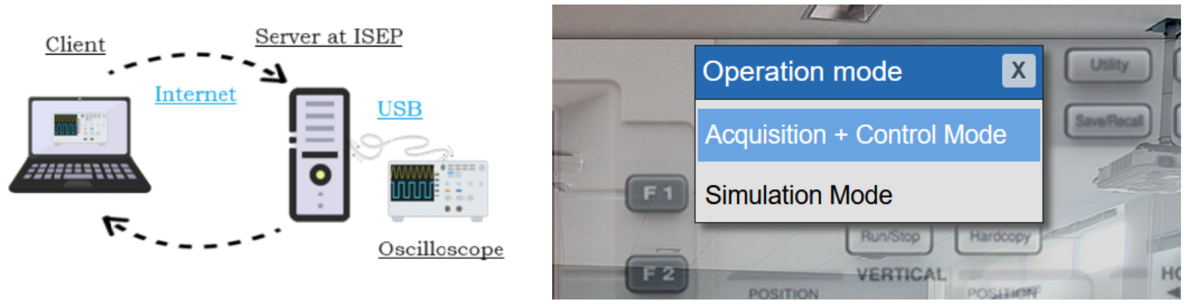
data points. We have created an online form for reporting bugs, limitations and suggestions, now accessible to all users via the aforementioned '*Support*' menu.

2.2 Snapshot of the SW architecture

To our best knowledge, the app (http://osciloscopio.dee.isep.ipp.pt) works for the most popular browsers (Firefox, Edge, Chrome); while problems were reported by a couple of Safari/Apple users. The *Simulation mode* software runs mostly on the *Client*-side: all functions, waveform displays and calculations only depend on the *Client* computing resources, which is paramount for the sake of scalability, i.e. allowing multiple users to access the website simultaneously without straining the *Server* resources. The *Acquisition & Control mode* software works in a different way (Figure 1), as the communication between the *Server* and the real Oscilloscope must be tackled at the *Server* side.

Figure 1

Client-Server architecture and selection of the Acquisition & Control mode.



***Note: Left**: Snapshot of the Client-Server architecture in the Acquisition & Control mode. **Right**: operation mode selection at Power On*

The communication between the *Server* and the Oscilloscope is performed via USB. Thus, for each Oscilloscope that we want to control, we need a PC in its vicinity. The lab features 9 + 1 workbenches, each with basic test & measurement equipment and a PC (9 for students peruse). In the future, we intend to host each *Server* in a single-board computer (SBC), to make it independent from the PC. *Client-Server* communication can be achieved through the Internet or a Local Area Network.

Both backend and frontend are coded in *Node.js*, using *JavaScript*. Building on the MVC (Model, View, Controller) paradigm, the software architecture is designed to accommodate future database-dependent features and new functionality and ensuring scalability (without exponentially increasing complexity). Divided into models, views, and controllers, the application operates seamlessly, with routers triggering controllers upon HTTP request, which then execute actions and render views accordingly. This architecture allows for easy integration of new features, such as additional equipment or usage modes. Moreover, the application REST API foundation enables communication with third-party applications, catalyzing the integration with other services (e.g. *U=RIsolve* (Sousa et al., 2021), (Sousa et al., 2021)).

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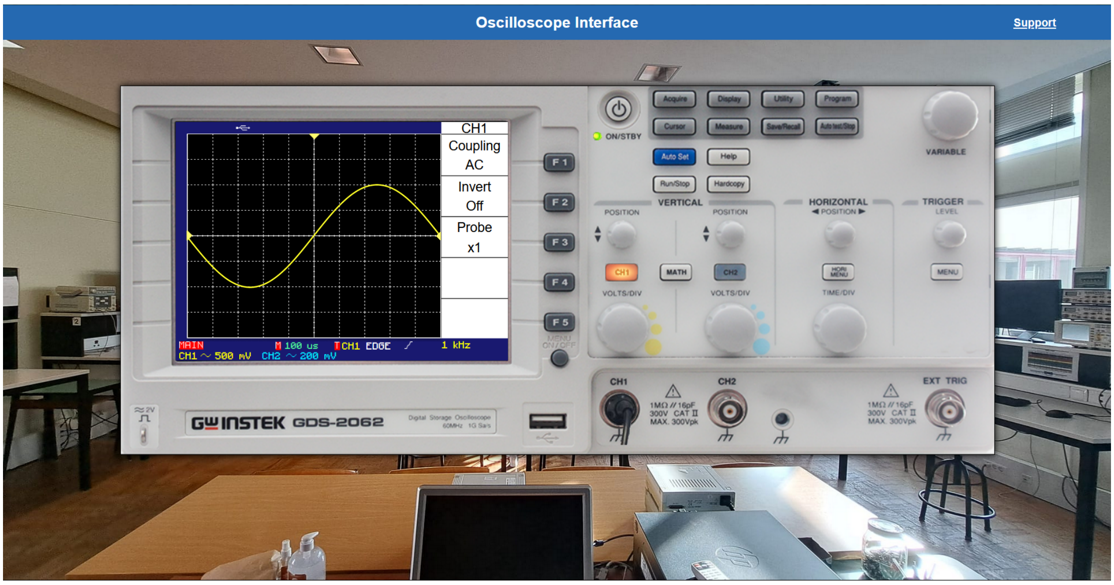
3 USER INTERFACE & EXPERIENCE

3.1 Application User Interface

The main window of the user interface represents the front panel of the (real) Oscilloscope (GW-Instek GDS-2062), with a front perspective of the lab in the background plane:

Figure 2

Oscilloscope app – main user interface (lab photo as background, for increased realism)

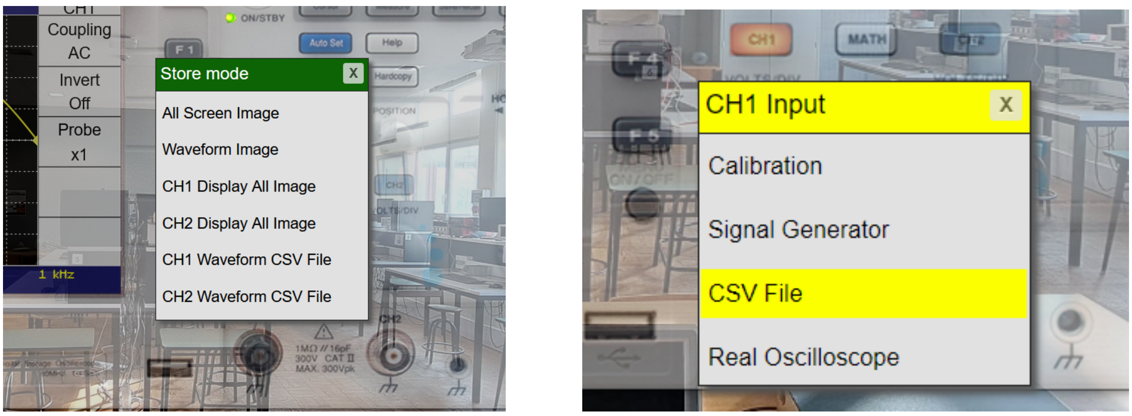


Note: Screenshot taken from the app (http://osciloscopio.dee.isep.ipp.pt) showing a sine wave signal (CH1 input).

We opted for *offcanvas* menus to organize the contents displayed upon selecting specific functions/commands, for optimizing screen space and enhancing user interaction, as exemplified in Figure 3 for the 'hardcopy' (screen/waveform data storage), on the left image, and Channel 1 (CH1) input source selection, on the right image.

Figure 3

Example of two offcanvas menus – 'hardcopy' and 'CH1 Input'.



Note: Offcanvas menus appear (different content), upon clicking buttons such as 'Power', 'CH1 input', 'CH2 input' and 'hardcopy'.

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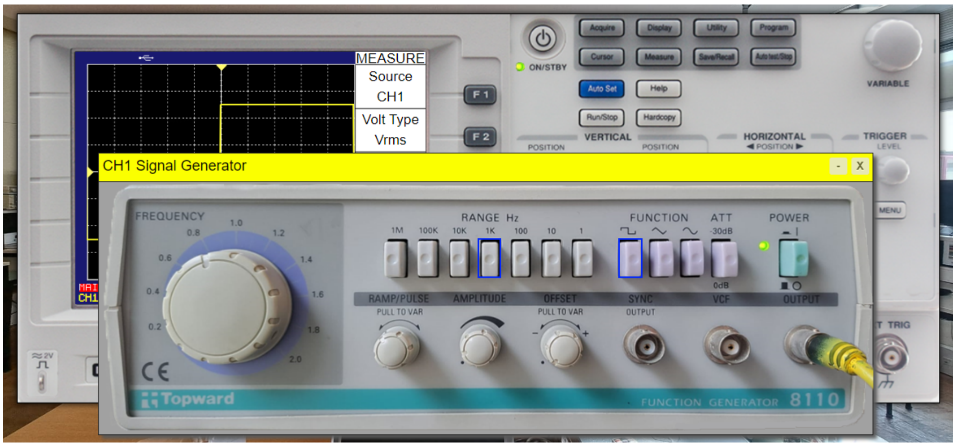
Upon selecting the 'Simulation mode' and then the 'Signal Generator' input (as illustrated in Figure 3, image on the right-hand side), the floating window shown in Figure 4 pops-up, enabling to configure the input signal for CH1[1].

Figure 4

Signal Generator pop-up & sliding window:



Note: Controls are handled by mouse clicking: on/off controls such as 'RANGE' or 'FUNCTION' are selected with the left button; rotating knobs (e.g. 'FREQUENCY', 'AMPLITUDE') are controlled by the left button to decrease and right button to increase. The Signal Generator window may be moved around, and minimized/closed after setting the input signal.

The colors, typography and menus of the user interface try to mimic (as far as possible) the real equipment. This design approach aimed at making the user interface as realistic as possible, and thus easier to associate with the physical instrument. As outlined next (Section 3.2), this was one of the most positive aspects highlighted by the students.

3.2 User experience

To assess the user experience of *Oscilloscope Simulator* app, an online questionnaire was conducted with TCIRC students. This questionnaire was composed of four different parts:

- i) Characterization of the sample (age, gender, number of enrolments in the TCIRC course, whether being a worker-student or not);
- ii) Whether the students had used the app (if not, identify the reason for not using it);
- iii) User experience, made up of 4 questions associated with a Likert scale – 1 (totally disagree) to 5 (totally agree);
- iv) Two open questions to report positive and negative aspects. The questionnaire was available for two weeks after the students had used the tool to prepare Lab Script 2.

We estimate that 248 students were attending the TCIRC course at that time, while 195 of them (78.6%) answered the questionnaire. Students' age ranges between 18 and 52, but most of them (79,0%) are 21 years old or under. Regarding gender, 87.7% are male and 10.8% female (1.5% preferred not to answer). Concerning the number of enrolments in this course, 149 students (76.4%) are taking it for the first time.

Most students (91.9%) had used the Oscilloscope Simulator at least once (when they answered the questionnaire) and 83.9% of them found the app easy and enjoyable to use, stating that it allowed them to: i) understand the

[1] For CH2, the background color of the input source selection and the top bar of the Signal Generator window would be blue (instead of yellow, for CH1), to mimic the colour of CH2 trace and button in the real equipment).

operation of the main oscilloscope commands (81.0%); ii) understand the operation of the signal generator (77.1%); iii) prepare for Lab Script 2 work (84.9%).

The open-ended questions will be thoroughly analysed as future work. However, in a preliminary assessment, the most mentioned positive aspects of the app were: i) enabling the use of equipment that is normally not accessible at home and allowing studying/preparing at home; ii) being intuitive and easy to use; iii) being realistic (very similar to what they find in the lab). The most mentioned negative aspects were: i) the lack of an instruction guide; ii) some functions/buttons being disabled; iii) the adjustment of the rotating knobs should be simpler, such through an animation.

4 USE CASES

This section overviews two paradigmatic use cases (as application domains *i)* and *ii)*, in the *Abstract*) of the *Oscilloscope Simulator* mode, in the context of the TCIRC course.

4.1 Lab script 2 preparation

The *Oscilloscope Simulator* has been used for off-class (prior) preparation of Lab Script 2. In the lab class, the students perform a set of experiments for assimilating the basic operation and functionality of the Oscilloscope and of the Signal Generator, in teams of two (per workbench). Each team has to follow the lab script step-by-step instructions, to execute the corresponding actions (implement the circuit, setup the test & measurement equipment, take measurements and make calculations/reasoning) and to answer (along the execution) a number of questions in a Moodle test (e.g. numerical values resulting from direct/indirect measurements, multiple choice, true/false, association), which is considered (together with all the other lab scripts grading) for the overall evaluation of the group, at the end of the semester. The corresponding "preparatory" work materialized through another (individual) Moodle test that should be done autonomously in the week preceding its lab execution: in the specific case of Lab Script 2, students performed its preparation from 11 to 18 of march and then executed it (in the lab class) between 19 and 23 of march (2024). All preparatory tests are averaged for individual grading.

The preparatory lab tests aim at ensuring that each and every student is properly prepared before going to the lab class to execute the experiments, for securing personal and equipment safety as well as for a smooth and efficient workflow (Oliveira et al., n.d.) . The preparatory tests are quite oriented to the practical work and circuits that are going to be implemented and experimented in practice, requiring the student to perform circuit analysis (using different circuit analysis theorems, algorithms and methods, such as the ones mentioned in (Sousa et al., 2021), (Sousa et al., 2021), (Oliveira et al., 2013), (Macedo et al., 2021), (Oliveira et al., n.d.) and simulation (mostly using QUCS (QUCS - Quite Universal Circuit Simulator, n.d.), which we have previously extended with additional functionality), in order to compare the analytical/simulation results with the experimental ones.

A total of 226 students performed the preparatory test for Lab Script 2 and (supposedly) had to use the *Oscilloscope Simulator* app and submit a couple of output waveforms through the Moodle quiz (specific boxes exist to upload the files). As reported in Section 3.2, most students found this app quite useful to prepare for the lab class and operate the real equipment, as we have initially perceived through personal interactions with some students and later confirmed through the responses to the questionnaire.

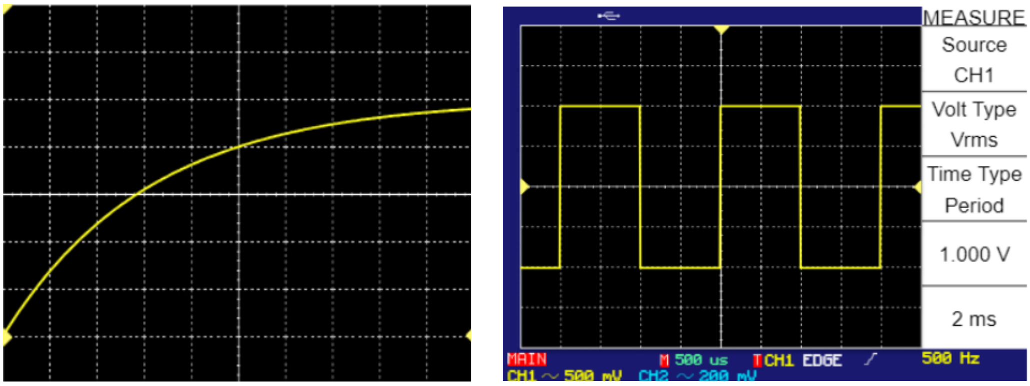
4.2 First lab test

The *Oscilloscope Simulator* was later used in the first lab test, along the week of 15-19/apr/2024, which has been performed in shifts of 9 students (1 per workbench), in two different ways/exercises:

- **Exercise 1**: we used the simulator to generate several waveforms for transient analysis of a capacitor charge/discharge RC-series circuit; each version of the lab test could have a different waveform/setting (Figure 5 – left).
- **Exercise 2**: students had to use the simulator (along the test) to generate and visualise a specific waveform and signal parameters; each version of the lab test could request a different waveform, concerning format (sine, square, triangular), amplitude (AC + DC) and period (Figure 5 – right).

Figure 5

Example waveforms/screens used in one of the lab test versions (for one students' class):



Note: Exercise 1 (left): we provided the waveform/screen and vertical/horizontal settings of the Oscilloscope, asking the students to determine the U_{max} and time constant values and write the $u_c(t)$ equation. Exercise 2 (right): we provided the characteristics of the signal (in this example: pure square wave, $f = 500$ Hz, $U_{max} = 1$ V), requiring the students to configure the side menu to indicate RMS voltage and period; then, students had to call the professor to check it in loco.

This was quite challenging for the web *Server* because there were 9 students doing the lab test simultaneously in 9 different PCs (*Clients*), requiring it to work properly and with the lowest possible delay. Along that week, over 230 students performed the lab test. Mind that while a maximum of nine students could be doing the test at the same time, the web app should be accessible to all other students as well (to practise for the lab test). This scenario stressed the importance of attaining a well-balanced structure between front-end and back-end (*Client* and *Server*).

Overall, these use-cases have been paramount to evaluate the app performance and the users' experience in two different contexts (off-class training and lab test) and time periods.

5 CONCLUSION

We consider this *Oscilloscope Interface* app a significant advancement to the state-of-the-art in e-learning tools for simulation and remote experimentation. Importantly, this tool has been developed by a student for their peers, which adds extra layers of motivation and validation for all parties.

This paper overviewed the software architecture, exemplified the application of the *Simulation mode* in the context of a course with 250 students, and sampled their user experience based on personal interactions and a specific questionnaire. While we just present the main conclusions of this study, we will now perform a thorough analysis to get more insight and correlations between different dimensions.

The proposed e-learning tool introduces several innovative aspects such a realistic user interface and the remote acquisition/control capability. We intend to further enhance the app functionality and user experience, according to previous plans and based on student's feedback. We are considering improving the manipulation of certain commands/knobs, adding the XY visualization mode and beginners'-friendly on-line help. We will also consolidate the *Acquisition & Control mode* (out of the scope of this paper), namely evaluating different SBC platforms for hosting the app servers.

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We would like to acknowledge the collaboration from the TCIRC teachers' team and students, which has been paramount to assess the *Oscilloscope Simulator* in a realistic academic context, enabling a preliminary evaluation of their experience (Section 3.2) and to shape the evolution of this educational tool.

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