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Pocket-Sized Portable Labs: Control Engineering Practice Made Easy in Covid-19 Pandemic Times

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Abstract: New pocket-sized laboratories are proving to be an excellent tool as complementary equipment that students and lecturers can deploy to test control engineering design techniques. Here, the description and outcome results of an IFAC activity funded project entitled as Pocket-Sized Portable Labs: Control Engineering Practice Made Easy are presented. The project was executed in Portugal, from January 2021 to the end of June 2021, during the SARS-CoV2 pandemic. The global aim of this project was to motivate pre-university students to enroll in control engineering courses by showing and demonstrating that simple practical experiments may be easily accomplished using portable pocket-size laboratories.

Keywords: Portable Laboratories, Control Engineering Education, Arduino.

1. INTRODUCTION

Small sized portable laboratories (Kalúz et al., 2019), also known as pocket-sized laboratories (Juchem, et al., 2020), carry-home mobile platforms (Steinhauser et al., 2017) or take-home laboratory kits (Rossitter et al., 2019), are gaining popularity (also) within control engineering lecturers and students. Some of the reasons justifying this popularity are due to be easily transported and can be used anywhere and anytime. Pocket-sized laboratories become yet more relevant during the SARS-CoV2 pandemic, allowing students to continue performing some practical experiments at home while living confined (Chancharoen and Maneeratana, 2020; Moura Oliveira and Soares, 2021). While pocket-sized kits can be based on several microcontrollers and microprocessors, the clear majority is based on Arduino and Raspberry Pi platforms. This type of digital devices have been applied for teaching/learning purposes in a diverse range of scientific areas (e.g.: West et al., 2017; Organtini 2018; Wang et al., 2019; Alvarado and Maestre, 2019; Oteri, 2020; Ari and Meço, 2021) within the scope of STEM (Science, Technology, Engineering and Mathematics). The pocket-sized laboratory selected to be used as demonstration kit in this project is based on an Arduino: the Temperature Control Laboratory (TCLab) proposed by (Hedengren et al., 2019; Park et al., 2020; Hedengren, 2021). Reasons justifying this kit selection in this work are presented in section 3.

The authors of this paper are members of APCA (Portuguese Association of Automatic Control) which is a national member organization of IFAC (International Federation of Automatic Control). The mission of these two associations includes the promotion of automatic control science and technology. Motivating secondary students to pursue university Engineering studies with automatic control courses, fits well within APCA and IFAC mission. Within this scope, a project was submitted by a set of Portuguese researchers to the IFAC activity funds entitled “Pocket-Sized Portable Labs: Control Engineering Practice Made Easy”. This project was funded by IFAC and the associated activities were carried out from January 2021 to the end of June 2021 in Portugal. The project activities were organized to involve both secondary schools’ teachers and their students. One way to motivate students for control engineering is to convince STEM teachers to integrate simple practical laboratory experiments within their teaching/learning activities. The participation of both teachers and students in Programming and Robotics clubs is another component in which portable laboratories can be implemented.

The remaining of the paper is organized as follows: section 2 presents the project activity overview; Section 3 presents a basic TCLab description and section 4 presents aspects regarding a workshop performed for secondary teachers. Section 5 presents some results obtained from teachers by answering two questionnaires regarding the use of portable laboratories and workshop perceptions. Section 6 concludes the paper and outlines some future directions to continue the project.

2. PROJECT ACTIVITY OVERVIEW

This section presents an overview of the IFAC activity funded project entitled Pocket-Sized Portable Labs: Control Engineering Practice Made Easy. This project was proposed to IFAC and executed under the auspices of the Portuguese Association for Automatic control (APCA). It is part of both IFAC and APCA mission to promote Automatic Control. Thus, within this scope, this project was proposed with the main objective to motivate secondary teachers and students to control problems. How? By showing and demonstrating that simple practical control experiments may be easily accomplished using portable pocket-sized laboratories.
The activity was designed to be performed in two stages: 1) motivate teachers working in engineering areas related to automatic control to use portable laboratories in their teaching; 2) with the help of the teachers which participated in stage 1, motivate their students for control engineering. It is important to state that when the project was submitted to the IFAC activity funds before the 15th of October 2020, it was intended to be fully executed using a presential mode beginning in January 2021. As the SARS-CoV2 pandemic situation in Portugal got worse, some activities had to be conducted remotely.

The pocket-sized laboratory selected to be used within this project was the Temperature Control Lab (TCLab) (Hedengren et al., 2019; Park et al., 2020; Hedengren, 2021) to be briefly described in the next section. The reasons which based this selection are the following: i) the TCLab is sold fully operational, not requiring any assembly of parts; ii) the kit simplicity; iii) it can be programmed using several programming languages; iv) there is an excellent freely available repository of supporting information in (Hedengren, 2021); v) the TCLab has been used successfully within control engineering education experiments regarding the digital implementation of industrial controllers (Moura Oliveira and Hedengren, 2019; Moura Oliveira et al., 2020).

The project execution started with the acquisition of 70 TCLab kits. Then, the plan was to organize:

- A workshop to motivate teachers to use TCLab in their teaching/learning activities.
- Three visits to secondary schools, to motivate students to control engineering and demonstrate the TCLab. These activities are described hereafter.

3. TEMPERATURE CONTROL LABORATORY: BASIC DESCRIPTION

The TCLab started by using an Arduino Uno, and currently is based in an Arduino Leonardo. A TCLab photo (Hedengren, 2021) is presented in Figure 1.

![Fig. 1 TCLab kit- Temperature Control Lab.](image)

As it can be observed from Figure 1, TCLab uses an Arduino shield with two transistors, acting as heaters (control system actuators) and two transistors acting as sensors. For more detailed information regarding the TCLab transistors specifications please refer to (Hedengren, 2021).

The TCLab Arduino is connected to a computer via a USB cable and the shield with the transistor heaters and sensors is connected to the electric grid power supply through a 5V USB plug. The TCLab can be programmed using several frameworks, such as Python, MATLAB/Simulink and OCTAVE. Introductory programs and models are freely available in (Hedengren, 2021).

As one of this project objectives is to motivate secondary teachers and students to engage in control engineering experiments, it is important to present the control problem in simple terms. An illustrative block diagram incorporating the TCLab within a closed loop control system is illustrated in Figure 2. The control system objective, in this example, is to control the temperature in transistor 1 (T1) casing. In Figure 2: r, represents the reference input, which, in this case, corresponds to the desired temperature (in °C) to be achieved in T1; y, represents the system control output corresponding to the temperature measured in T1; e, represents the error signal; based on the error signal the controller determines the control signal, u, corresponding to the desired heater actuator level. The time is represented in the continuous domain using t and in the discrete time domain as kTs, with Ts representing the sampling time and k the sample index.

![Fig. 2 Closed-loop block diagram incorporating TCLab.](image)

### 3. WORKSHOP FOR TEACHERS

Due to the SARS-CoV-2 confinement in place in Portugal when the project was executed, it was not possible to organize a presentational workshop for teachers. Thus, the workshop (see Figure 3) was organized online, as a Webinar, through the Zoom platform, on the 14th of May 2021 between 17h-18h. A call for participation in this workshop was sent to a list of teachers working in secondary/professional schools in Portugal.

![Fig. 3 Webinar poster.](image)
Given that the activity topic is control engineering, most targeted teachers belong to groups designated in Portugal as follows: Electronics, Automation and Computers; Mechatronics. Despite that, there were teachers interested from other groups (e.g. Physics and Chemistry) which registered and participated in the Webinar. There were 47 teachers from Portuguese schools registered in the Webinar. The location of the schools in which they work can be visualized in the maps presented in Figure 4.

From the 47 registered teachers, 37 participated in the Webinar (see print screen photo presented in Figure 5).

The Webinar started with a portable laboratories overview with special relevance on the application in control systems. TCLab was presented highlighting the components, the functionalities, the programming tools and its suitability to be used in this restrictive environment due to the SARS-Cov-2 pandemic. Practical demonstration examples were presented such as: disturbances introduction and compensation (by fanning the transistor acting as sensor with a paper) and changing the input temperature reference values to confirm set-point tracking. The session was then opened for questions of the audience to clarify some points. A TCLab kit was offered (sent by mail) to every teacher which participated in the Webinar.

4. VISITS TO SCHOOLS AND DEMONSTRATION SESSIONS

In order to present TCLab to students, the project team visit three schools, namely:
1. Monserrate secondary school located in the city of Viana do Castelo. This visit took place on the 29th of April 2021.
2. Avelar Brotero secondary school of located in the city of Coimbra. This visit took place on the 4th of May 2021.
3. Fundão Secondary School located in the city of Fundão. This visit took place on the 20th of May 2021.

In each visit a presentation was made to both students and their teachers (see photos presented in Figures 6 and 7). The overall objective was to motivate students to continue their university studies in Engineering courses involving control engineering. The presentations included:
- Introduction of control terminology and configurations;
- Examples regarding the practical relevance of control engineering;
- Portable laboratories and TCLab;
- TCLab control demonstrations;
- Open debate for questions.

A set of TCLab kits was offered to the students of every school visited. Note that given the short time window assigned to this project execution it was not possible to obtain perception results regarding the use of TCLab by these students.
Despite the activity short period execution time span two questionnaires were designed to collect some information and feedback from the teachers that registered and participated in the Webinar. The first questionnaire was conducted before the Webinar and the second one after the Webinar took place, as in a pre and post-query format. The questionnaires filling was anonymous. Note that answering the pre-questionnaire (the first) by the 47 teachers willing to participate in the Webinar was mandatory; only after the questionnaire was fulfilled and submitted, the attendees received the link to the online Webinar. On the other hand, the post-questionnaire filling was on a voluntary basis. This conditioned the number of completed surveys received in the pre and post-queries.

The first questionnaire aimed to assess teachers’ perceptions on the use of new teaching/learning tools/strategies, in particular, regarding the use of portable laboratories teaching kits based on Arduino (as concept demonstrators). The questionnaire was divided in three parts: Teacher characterization (gender, age, school, course, disciplinary group, cycle of studies); Teacher perception of the potential and applicability of kits (TP); and Personal motivation (PM).

The second part, directed to access teacher’s perceptions regarding the potentiality and applicability of didactic kits, included 12 questions but only the 5 listed below are analyzed in this paper:

- TP1: Didactic kits promote learning processes focused in the principle hands-on, minds-on.
- TP2: Didactic kits enable the developing of innovating methodologies.
- TP3: Didactic kits promote the cooperation dynamics between teachers.
- TP4: The use and construction of didactic kits enable students to enhance their learning. The results are represented in Figure 11.
- TP5: Didactic kits promote students’ interest and motivation.

A five-points Likert scale was used to classify these statements, adopting the following correspondence: 1 (Strongly Disagree), 2 (Disagree), 3 (Indifferent), 4 (Agree), and 5 (Strongly Agree).

The last part of the survey, Personal motivation to the use of didactic kits, included six yes/no type questions where three are detailed below:

- PM1: Did you already used didactic kits? If yes, in what activities.
- PM2: Are you aware of the term STEAM (Science, Technology, Engineering, Arts and Mathematics)?
- PM3: Are you motivated to use new teaching/learning methodologies?

It included also two optional open questions:

- PM4: How do you see the implementation of Arduino-based teaching kits in your area?
- PM5: What kind of experiments using Arduino-based teaching kits can you carry out in your teaching area?

32 teachers filled the first questionnaire (65.6% masculine and 34.4% feminine) with ages ranging from 36 to 66 years old. Regarding the teaching courses, 17 teachers teach Electronics, Automation and Computers or Electrotechnics; 7 teach Computers and Electronics, 4 teach Physics and Chemistry, 1 was responsible for a student’s robotic club and 2 teach in other courses. Most attendees are from secondary schools. Worth registering the presence of 1 attendee from the first cycle (students from 6 to 9 years old) and 2 from the second cycle of studies (students from 10 to 11 years old).

The statements that received only positive answers (4 and 5 in Likert scale) were TP1, TP2, and TP5. Regarding TP1 statement, all teachers agree (35.4% Agree, and 65.6% Strongly Agree) that didactic kits promote learning processes focused in the principle hands-on, minds-on. TP2, on the use of didactic to enable the developing of innovating methodologies, registered a stronger agreement with 15.6% Agree and 84.4% Strongly Agree. TP5, received 21.9% Agree, and 78.1% Strongly Agree.

Regarding using didactic kits to enable and promote cooperation dynamics between teachers, TP3, registered a disagreement, a no opinion and 43.8% Agree, and 50.0% Strongly Agree. TP4 registered one no opinion and 28.1% Agree, and 68.8% Strongly Agree.

In summary the feedback regarding teachers perception of the potential and applicability of kits was very positive, as most of the marks selected are 4-5 (Agree and Strongly agree, respectively).

As it can be observed from Figure 8a) most teachers (87.5%) have used didactic kits in their teaching activities (PM1) and they are strongly motivated (96.9%) for using new teaching/learning methodologies (PM3). Most of the teachers are familiarised with the term STEAM, PM2, (68.8%).
The questionnaire was divided in three parts: Teacher characterization (gender, age, school, course, disciplinary group, cycle of studies); Teacher perception of the potential and applicability of kits (TP); and Webinar Perception (WP).

The first and second parts of the questionnaire were equal to the ones in the pre-questionnaire. The idea to keep the second part of the survey was to infer if teachers’ opinions changed after attending the Webinar and learning about TCLab and portable kits.

The third part of the survey, Webinar Perception, included nine questions where three are detailed below:

- WP1: How do you classify the kits as a useful tool to support teaching/learning?
- WP2: How do you classify the relevance of the Webinar experiments in the development of student’s interdisciplinary competences?
- WP3: How do you classify the Webinar in terms of the innovation of presented topics?

A five-points Likert scale was used to classify these statements, adopting the following correspondence: 1 (Strongly Disagree), 2 (Disagree), 3 (Indifferent), 4 (Agree), and 5 (Strongly Agree).

Two optional open questions were also included:

- WP4: What topic would you like to see addressed in an upcoming webinar?
- WP5: Would you like to participate in an introductory workshop on using TCLab?

Only 13 teachers filled the first questionnaire (69.2% masculine and 30.8% feminine) with ages ranging from 36 to 60 years old. The teaching courses and schools are some of those in the pre-questionnaire. Most attendees are from secondary and 3rd cycle schools and none from the 1st cycle and 2nd cycle of studies.

Regarding teachers’ perception towards the Webinar, and focusing on TCLab, the attendees scored questions WP1 to WP3 as:

- WP1: 46,2% Agree, and 53,8% Strongly Agree
- WP2: 30,8% Agree, and 69,2% Strongly Agree
- WP3: 76,9% Agree, and 23,1% Strongly Agree

In the WP4 optional open question we registered the following answers:

- “Application in contexts involving Artificial Intelligence”;
- “Mechatronics”.

In WP5, 85,7% of the attendees stated that they would like to participate in an introductory workshop on using TCLab.

In summary, the feedback from teachers in both questionnaires towards the Webinar, and focusing on TCLab, allows us to infer the teachers’ motivation to use kits as well as to conclude the relevance and suitability of using the pocket labs in several cycles of studies. We believe that motivated teachers allow motivated students. TCLab and other kits may be a suitable tool to promote this teaching/learning process.
6. CONCLUSION

The project entitled Pocket-Sized Portable Labs: Control Engineering Practice Made Easy, sponsored by the IFAC Activity funds was presented. The project was executed from January 2021 to the end of June 2021, in Portugal during the SARS-Cov-2 pandemic. The project involved the organization of a Workshop for teachers working in STEM with emphasis to the areas of industrial automation and control engineering. The workshop objective was to motivate teachers to incorporate pocket-sized laboratories to carry out control engineering experiments within their teaching/learning activities. Three visits to secondary schools were conducted after the workshop. In these visits it was possible to interact with both students and their teachers by: i) Presenting motivating real-world applications of control engineering; ii) Presenting portable laboratories for control and robotics, with emphasis given to the Temperature Control Laboratory (TCLab); iii) Demonstrating the temperature control using TCLab. The set of 70 TCLab kits was offered to teachers which participated in the Workshop and to students of the three visited schools.

Teachers’ opinion towards the Webinar and the kits was quite positive which points out the importance of using the pocket labs in several cycles of studies. These hands-on activities motivates teachers and, as a consequence, students to the teaching/learning process.

Thus, it is expected that during the academic year of 2021-2022 some experiments using TCLab will be executed in some of this schools and hopefully contribute to motivate students for automatic control. Future work is planned to obtain secondary school students’ perceptions regarding the TCLab portable laboratory use.

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