Household Appliances Identification: Hands-on integrative workshop and its adaptation to a social distancing context

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***Abstract*—Theoretical and practical knowledge integration is essential in Electrical Engineering. Throughout the degree, students must tackle specific problems where they can put into practice difficult concepts and test their learning.**

Taking this into consideration, an integrative workshop is implemented in the third year that seeks to strengthen skills such as: analysis and design of signal conditioning circuits, designing and printing circuits, signal acquisition and processing, pattern recognition and classification, integration of a system. The workshop is based on the topic of load identification which is a challenging problem, suitable for developing multiple electrical engineering concepts and also an interesting subject for the initiation of the students to research.

This article shares the 2019 edition experience and its adaptation to non-classroom classes in 2020 in the context of social distancing restrictions due the coronavirus disease.

The 2019 didactic proposal and the necessary modifications for 2020 are presented and analyzed. Although loosing the fruitful interaction between teachers and students in the lab in 2020, most of the hands-on activities could be maintained helped by the use of USB oscilloscopes/analyzers that give students the functionality of a lab at home. It is concluded that both editions, in spite of their different teaching modalities, achieved good academic results.

***Index Terms*—Integrative workshop, Electrical Engineering degree, load identification**

I. Introduction

In recent years, Uruguay has changed its energy mix with the introduction of high levels of renewable energies. Due to the high variability of renewable sources, the energy distribution companies must monitor and guide the load, specially the energy consumption at households. Knowing and influencing the ways in which household appliances are used can help manage the demand and adapt the load according to the availability of the renewable sources [1]. The problem of identifying appliances through non-intrusive monitoring (NILM - Non-Intrusive Load Monitoring) is a research area in full development [2], [3] that is being addressed by our department in collaboration with the national electricity company, *Administración Nacional de Usinas y Trasmisiones Eléctricas (UTE)*.

Our department, *Instituto de Ingeniería Eléctrica (IIE)*[1] is responsible for the technical courses in all the different profiles of the Electrical Engineering degree and postgraduate degrees. It also performs investigation in cooperation with private and public partners and has a long history of collaboration through agreements, such as the one that gave rise to this experience. The development of academic work by undergraduate and postgraduate students linked to research and development projects, with public and private sector companies, contributes to training on applied topics in direct collaboration with experts. In this context, it was considered highly motivating and formative to propose an integrative workshop in which the third-year students (of a five-year degree), designed a prototype for the identification of an appliance through the acquisition and processing of voltage and current signals.

The importance of workshops in the Electrical Engineering degree that allow to understand the usefulness of theoretical subjects, in particular, mathematics and physics, led to the proposal of an initial workshop in the first year of the degree [4], [5] . This activity confirmed the relevance of hands-on subjects, which not only generate specific learning but also transferable skills such as project-based activities and teamwork, since the beginning of the career. Correspondingly, it was understood that having a workshop integrating the knowledge developed in the middle of the degree could ensure continuity in the experience and a better preparation for the final degree project. The workshop in the second semester of the third year of the degree, allows the students to put into practice and incorporate the knowledge of courses of the third year such as Fundamental Electronics, Logic Design, Circuit Theory, Signals and Systems, and Programming. It also motivates them to understand subjects that are taught in the same semester such as Fundamentals of Machine Learning and Random Signals and Modulation, among others.

In 2019, this third year workshop was introduced as part of a restructuring of the Electrical Engineering degree. Two different workshop topics were proposed to the students ”Load monitoring” and ”Wireless Communications”. This article presents the implementation and results of the former.

The problem of load monitoring is suitable to introduce or strengthen basic concepts of electrical signals (active and reactive power, harmonic distortion, etc.), to practice circuit

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design, simulation and printing, and to apply signal processing and pattern recognition algorithms. Working with AC signals is also an opportunity to make students aware of safety rules and practices that must be a concern of every electrical engineer. Likewise, the problem allows also to initiate the students to research by being in touch with standards and state of the art publications, documenting adequately their work, and performing oral presentations.

The results of the 2019 experience was published inside the TAEE 2020 conference [6]. The current work is an extension that includes the changes introduced in 2020 to deal with pandemic restrictions that did not allow to have classes in laboratories. In particular, the workshop, held in the second semester of 2020, let the students to become familiar with the implementation of circuits and their survey, topics that could not be implemented in the previous semester due to the pandemic scenario.

The rest of the article is organized as follows: section II introduces load monitoring and related research . Section III presents the objectives and methodology of the workshop. The students' tasks, implementation details and experimental results are exposed in section IV including the differences between the modalities of the two editions of the workshop.

Finally, section V concludes this paper, summarizes the main results and lists possible lines of future research that could help improve the workshop.

II. Load monitoring related research

Characterization of the consumption of the different appliances is relevant both for users and for energy distribution companies. Having per appliance consumption information allows the user to make decisions for a more efficient use of energy and enables the company to define the required stimuli in order to guide the customers and match demand with generation. This is especially useful when there is surplus wind generation. Efficient use, in addition to economic return, results in reduction of environmental impact.

Appliances, the main component of household consumption, can be characterized by their electrical footprint as seen in figure 1. This can be short time or long time, depending on the duration of the transitory and the work cycles. The consumption analysis enables, for example, to take advantage of "smart" plans in which the consumer may take the decision to postpone some tasks and accommodate them to off-peak schedules (e.g. perform the laundry after midnight).

The identification of working appliances, by sensing upstream at the energy meter in conditions of aggregate consumption, is specially useful. In this case, the electrical signals in a certain moment carry the aggregated information of all the appliances in use at that moment. This is called non-intrusive monitoring since it can be performed without intervening in the electrical installation or measuring near each appliance. Although being desirable, this approach constitutes an open problem that implies sources separation and is currently in active research [2], [3], [7]–[10] A complete review of disaggregation techniques until 2016 can be found in [3] and more recently in [11], [12].

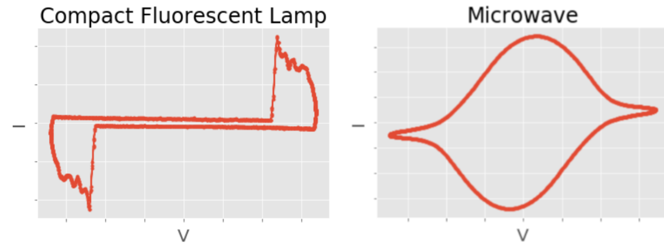

Fig. 1: V-I diagrams of household appliances in the PLAID dataset [15].

A simpler problem is the identification of an appliance when only one is monitored at a time. This is addressed for example in [13], [14] as a supervised problem. The workshop presented in this article focuses on this problem.

For the interested reader, in [6] a literature review on load monitoring can be found along with a brief review of non-intrusive monitoring products and services offered in the market.

III. Workshop Proposal

The workshop addresses the problem of household appliance type classification given the acquisition of a few seconds of the current and voltage signals. It is assumed that only one appliance is monitored at a time.

In the workshop, students are proposed to do the following activities:

1) Design and implementation of circuits for the conditioning of voltage and current measurement signals,
2) Acquisition of signals of different types of loads,
3) Analysis of the signals in time and frequency,
4) Extraction of relevant characteristics such as VI diagrams, powers, harmonic distortion,
5) Use of classification algorithms, training based on the extracted characteristics and performance evaluation,
6) Integration of the different blocks of the system,
7) Test and use of the designed prototype,
8) Documentation of the work in an article.

The work is carried out over a semester in groups of three or four students with weekly practical sessions that include tutorials, hands-on work, and evaluation of the proposed practices. At the end of the period, each group prepares a report (in article format) describing the devised solution and the experimental results. The classification evaluation is carried out on a public dataset [15] and on a dataset compiled with the records acquired by the student groups using their designed prototypes.

The first instance of the workshop was held on the second semester of 2019. In the second semester of 2020 the second edition was held in a non-classroom modality with the sessions done by conference calls and all the hands-on activities done

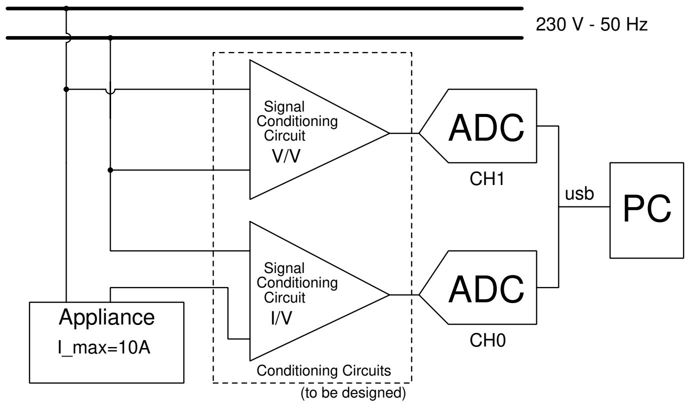

Fig. 2: Block diagram of the proposed solution. The design focuses on the conception of the two central conditioning signal paths required to acquire the current and voltage waveforms in the appliance.

at home by the students. [2].

The teaching was carried out by a mixture of teachers from the Signal Processing, the Electronics and the Electrical Power departments.[3]. The students were also from several different profiles within the Electrical Engineering degree (signal processing, electronics, power) which yielded rich discussions within the groups.

A. *Objectives for the students*

The main objective of the workshop is, given a single household appliance connected to the network, identify the type of appliance (within certain defined types). The type of appliance must be identified given the acquisition of a few seconds of the voltage measured in terminals of the appliance and the current consumed by the appliance.

The particular objectives are:

1) To design a system that allows to measure the voltage in terminals of an appliance and the current consumed by the appliance. The signals must be conditioned in order to correctly and safely acquire them by a given analog to digital converter.

   Figure 2 presents a block diagram of the desired system outlined with dashed lines. The design focuses on two main adaptors/transducers:

   Voltage / voltage transducer: to adapt the alternating voltage in appliance terminals (230 V - 50 Hz) at acceptable levels for the ADC, introducing a given error (in amplitude and phase) at 50 Hz. It should be considered that eventually filtering of signals above 500 Hz will be required.

   Current / voltage transducer: to acquire the values of current consumed by the appliance (restricted to the range 40 mA to 10 A) at values of admissible voltages for the ADC, taking advantage of the best possible way its benefits (in terms of its accuracy and resolution), having a good system sensitivity, and considering that it would be measured in a noisy environment to characterize. As part of the specification it was established that split core current transformer will be used with a nominal transduction constant kI = 1/30 V/A. The design problem was limited to amplifying a voltage, since some equipment consumes small currents (from order of tens of mA, for example LED lamps or compact fluorescent lamps). However, it should also be taken into account, that the transducer should work for currents of up to 10 A and therefore, for this current value, the output voltage of the Amplifier circuit could not exceed ADC ratings.

   In Figure 2, protections against overcurrents (overload and short circuit), as well as against indirect contacts are not shown but should be included in the designed solution.

2) To analyze the voltage and current signals in time and frequency domains, in order to understand the typical electrical fingerprints and extract the features that could help discriminate the different types of appliances. Depending on the type of appliance and its construction, the contribution of resistive, capacitive and inductive components will be reflected in a short-term footprint with a distinctive *V-I image* and measurable features with significant discriminating power, such as power factor, harmonic distortion, etc. The IEEE-1459-2010 Standard [16] is considered for the definition of this kind of features. In order to be able to study this kind of signals and features before the whole system is finished, the public dataset PLAID[4] [15] is used. The PLAID dataset contains short time (2 to 5 seconds that includes the power-on transient) acquisitions of voltage and current signals of eleven different types of appliances: air conditioning fluorescent lamp, fan, refrigerator, hair dryer, heater, incandescent lamp, laptop, microwave oven, vacuum cleaner and washing machine. The signals, sampled at 30 kHz, were recorded in more than 50 households across Pittsburgh, Pennsylvania, USA between 2013 and 2014.

[2]Workshop students 2019: Nicolás Aguilera, Felipe Albanés, Martín Algorta, Gabriel Aramburo, Martina Balbi, Walter Barreiro, Jorge Coelho, Santiago Colman, Juan Pablo De Souza, Agustina Díaz, Sofía Duarte, Mathías Galeano, Romina Gaudio, Felipe Isi, Guillermo Mazzeo, Martín Ochoa, Francisco Pastorini, Diego Pereyra, Juan José Pérez, Joaquín Saavedra, Ignacio Salas, Guillermo Sosa, Matilde Sosa, Ilana Stolovas, Santiago Suárez, Micaella Toledo, Andrés Wilchinski
Workshop students 2020: Ivan Abatte, Julian Álvarez, Diego Belzarena, Sebastian Benítez, Rodrigo Gónzalez, Andrés Guido, Facundo Guillén, Joaquín Pérez, Bruno Pons, Facundo Rodriguez, Martín Ruggeri, Manuel Sánchez, Santiago Sarachu, María Victoria Tournier, Tomás Vázquez

[3]Workshop teaching team 2019: Martín Avas, Andrés Cardozo, Santiago Machado (Electrical Power Deparment), Álvaro Gómez, Ignacio Irigiaray, Camilo Mariño, Pablo Massaferro and Alicia Fernández (Signal Processing Department)
Workshop teaching team 2020: Germán Fierro (Electronics Deparment) Alvaro Gómez, Ignacio Irigaray and Alicia Fernández (Signal Processing Department)

[4]http://www.plaidplug.com/

3) To implement the classification of the appliances into a set of defined types. Different classifiers and sets of features will be tested and compared in term of their performance.

B. Materials

Each group of students receives a junction box where the developed measurement circuits must be mounted. The box was designed solving the power connections, the mechanical assembly of the components and the electrical protections. The voltage and current measurement circuits are galvanically isolated. In addition, the box has a differential magnetothermal circuit breaker, providing protection to people and appliances to be measured. Considering references [15], [17], market availability and costs, the current clamp SCT-013-000 was selected for current acquisition. This is an instrument that allows acquiring a voltage proportional to the input current and with an adequate frequency response to the proposed problem. The size of PCBs to be designed by the students is preset at $50mm \times 70mm$ to ensure proper assembly and sufficient space for the signal cables. The junction box has an IEC C14 10 A power connector and a schuko socket outlet with hinged lid, as seen in figure 3.

For the acquisition of the signals, the Analog Discovery 2 (AD2), an all-in-one USB oscilloscope and instrumentation system from Analog Devices[5], is used, as the analog to digital converter. It has a voltage range of ± 25 V and a resolution of 14 bit.

The WaveForms [6] software for the AD2 has the functionalities of a digital oscilloscope and helps visualize the behavior over time, the spectrum, spectrogram of a live or stored signal.

Designed circuits are simulated with the LTSpice[7] software and surveyed using the Network tool of the Wafeforms software.

Python scripts from the WaveForms SDK are used, in order to acquire and process samples of the signals in batch mode.

C. Outline of the workshop

The workshop is organized in weekly practical sessions of three hours each. Table I presents the student activities, the given tutorials and the evaluations carried on throughout the semester. The estimated average weekly dedication of a student is 8 hours during 15 weeks including all the activities (attending the practical sessions, studying, team working at home, programming, preparing reports, etc.)

1) Student activities:

A.1) Introduction to python. Loading and saving data. Manipulation of arrays. Plotting.

A.2) Analysis of V-I signals in time and frequency domain. Work with the PLAID dataset. Computation of features.

A.3) Becoming familiar with the AD2 and the WaveForms software. Acquisition and analysis of signals.

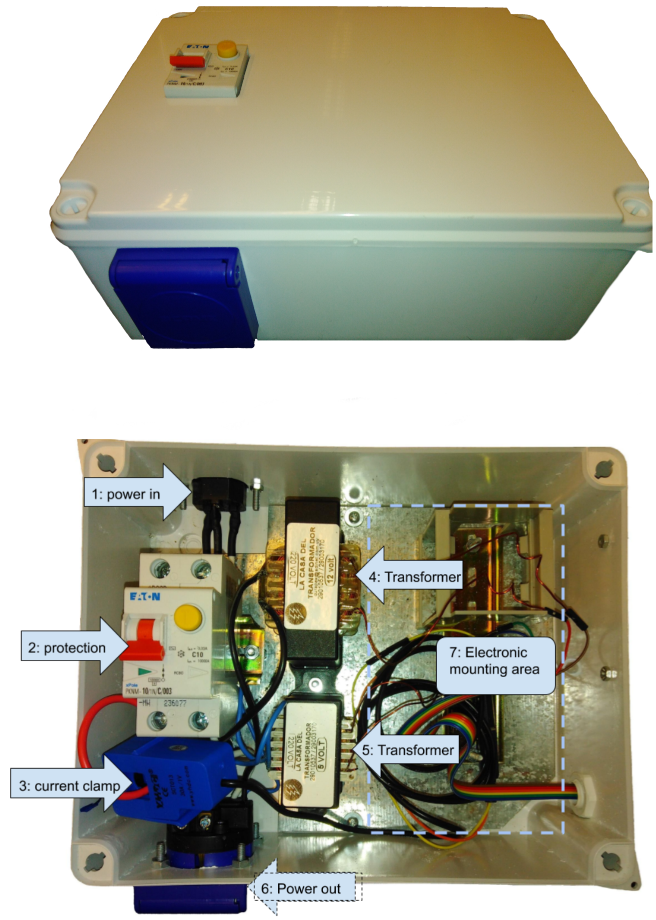

Fig. 3: Junction box for mounting measurement electronic circuits. It remains closed with 4 fixing screws whenever it is connected to electricity.
Contents: 1) IEC C14 10A power connector, 2) differential magnetothermal circuit breaker 30mA/10A, 3) Split core current transformer SCT-013-030 30A/1V , 4) Transformer 220V/12V 10VA, 5) Transformer 220V/5V, 6) schuko socket outlet with hinged lid, 7) Din rail and mounting area

Week	Tutorials	Group activities	Evaluation
1	T.1, T.2	A.1	
2	T.3	A.2	
3	T.4	A.2	A.2
4		A.3	
5		A.4	
6	T.5, T.6	A.5	
7		A.6, A.7	A.3
8		A.6, A.7	
9	T.7	A.8, A.9	
10		A.8, A.9	A.4-A.8
11		A.10, A.11	A.9
12		A.10, A.11	
13		A.12	
14			A.12, A.13

Tab. I: Activity outline throughout the semester. Please refer to the text for the information on tutorials and activities.

[5] https://analogdiscovery.com/

[6] https://reference.digilentinc.com/reference/software/waveforms/waveforms-3/start

[7] https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

A.4) Design of conditioning circuits. Study of alternatives and selection of a solution. Simulation of circuits in LTSpice. Discussion of the solutions.

A.5) Assembly of the DC source and the conditioning circuits in protoboard. Testing. Survey of the frequency response of the circuits. Comparison of surveys with the simulations.

A.6) Design and printing of PCBs.

A.7) PCBs assembling and soldering

A.8) Testing of circuits on PCBs. Survey of the end-to-end conversion constants for the voltage and current measurements. Placement of the PCBs in the junction box.

A.9) Classification. Rehearsal of different classifiers on the PLAID dataset.

A.10) Assembly of the end-to-end solution that can acquire the V-I signals and output the predicted class or class probabilities. Test with different appliances.

A.11) Acquisition of signals with the final solution. Acquisitions in the lab and at the students' households.

A.12) Preparation of a report in article format

A.13) Oral presentation of the results

2) Tutorials:

T.1) Introduction to the workshop. Load monitoring basics, applications. Household appliances and typical short-time V-I fingerprints. Possible features for load classification (active and reactive power, harmonics, power factor, VI diagram, etc).

T.2) Introduction to python. Data loading and saving, manipulation of data arrays with numpy, data plotting with matplolib. Use of Jupyter notebooks.

T.3) Acquisition and analysis of electrical signals. Acquisition with the AD2. Analysis in time and frequency domains. Transient and regimen. Windowing of signals. Fourier transform. Spectrogram.

T.4) Circuits for conditioning of electrical signals. Impedance adaptation. Galvanic isolation. Linearity/sensitivity. Noise reduction, capacitive and inductive noise coupling. Transformer basics. Differential amplifiers.

T.5) Layout design of PCBs. Use of an electronic design automation software. Schematics design. Layout definition. Component placing. Routing.

T.6) Printing of PCBs and soldering. Transference of circuit layout by heat. Use of iron perchloride. Soldering best practices.

T.7) Introduction to machine learning. Supervised learning. Training, validation and testing. Performance measurements. Classifiers, K-NN, Trees, Random Forest. Basics of python scikit-learn.

Additionally, the students received a complementary presentation on current security regulatory provisions and a short introduction to good practices when proposing an electrical design. The workshop also included an invited talk with a UTE expert who explained the relevance of the problem for the company and motivated the students about the prospects for professional development.

3) Adaptation to pandemic scenario in 2020: The first cases of Covid-19 in our country were registered on March 13, 2020. Restrictive measures were taken: border closures, suspension of flights, classes, religious services and mass events such as soccer tournaments and concerts. But the mandatory confinement of the population was not decreed. These measures coincided with the beginning of the first semester of the school year in Uruguay, which led the University of the Republic to decide to switch to a non-classroom teaching modality. At the beginning of the second semester with a controlled sanitary situation and few cases, there was a strict protocol that allowed some activities to be carried in person at the University but almost all the courses remained in a full non-classroom modality. In the 2020 edition of the workshop all the classes were done by conference calls. The controlled sanitary situation in the second semester allowed the students to carry out group activities and share equipment at home with the necessary personal responsible measures. The materials could also be delivered to each group of students following the protocols established at the University. Some of the activities of the course were adapted to the new situation. In 2019, a freer proposal was made in the electronic design due to the possibility of greater exchange with students in the lab. In 2020, given the uncertainty of non-classroom teaching, activities A.4 through A.8 were reformulated with a more complex but also more guided proposal.

The design of conditioning circuits (A.4) was staked out with a more complex structure but in a guided approach. The new proposal adds a programmable gain for the current conditioning circuit. This is specially useful to adapt in order to correctly measure the current of a wide range of appliances. Large gains are required to deal with low consumption appliances such as light bulbs to get adequate signals for the analog to digital conversion and avoid quantization problems. However, a side effect when using large gains in circuits with operational amplifiers is the problems caused by the offset. The new proposal addresses the offset problems and introduces the students to a feedback circuit that can be used to overcome this issue.

The use of programmable gains also introduces other interesting challenges for the students in hardware and software design as they have to select the adequate gain commanding electronic switches with the digital outputs of the AD2.

Section IV-C presents the main aspects of the 2020 proposal for the design of the conditioning circuits in the activity (A.4).

In the 2019 edition of the workshop the conditioning circuits were first implemented on protoboards and then moved to PCBs that were designed and assembled by the students in the lab. After testing the circuits on the PCBs, the circuits were mounted inside the junction box. All these activities were carried on in the lab with direct supervision of the teachers.

For the 2020 edition, without the possibility to work in the lab, it was decided that all the work of activity (A.5) on the conditioning circuits would be done on protoboards and would be tested using the AD2 USB oscilloscope. The junction box would not be opened by the students and it would be used only to have the voltage signal proportional to the line voltage on the appliance (the output of the 230V/5V transformer) and the voltage signal proportional to the current through the

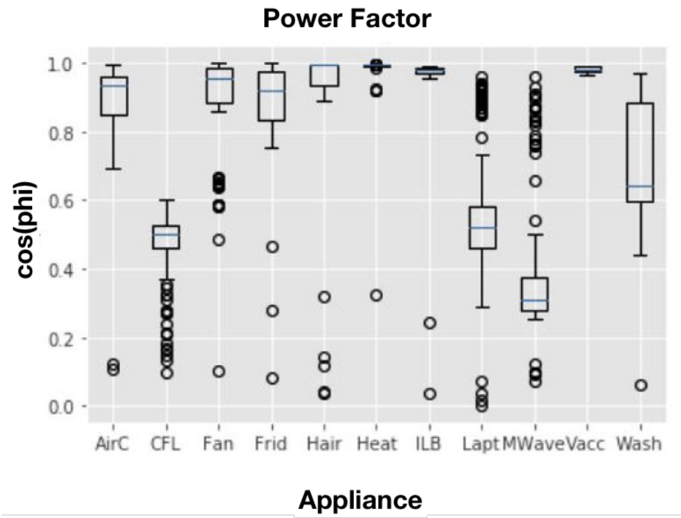

Fig. 4: Box plot for the simple analysis of the discriminant power of a feature.

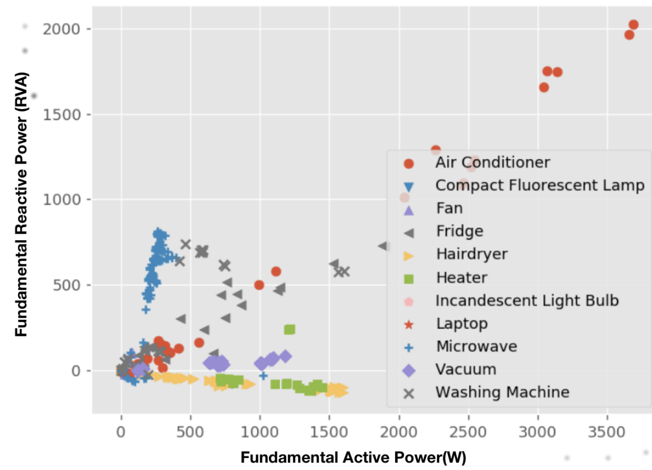

Fig. 5: Clusters in the fundamental active vs reactive power plane

appliance (the output from the current clamp). Regarding the activities (A.6) and (A.7) with PCBs, the layout design using an electronic design automation software was maintained but printing and assembling were laid aside. To mitigate the loss of this interesting activity, it was proposed to the students to investigate in the local market and in the web the different alternatives for printing the PCBs taking into account prices, qualities, lead times, etc.

IV. Development of the workshop

A. Data analysis

After an introduction to the course and to the subject of load monitoring, the students received a short tutorial on Python and Jupyter Notebooks. The third year students had already done other Programming courses earlier in the carrier using Pascal and C languages, but, for most of them, this was their first experience with Python.

The loading and analysis of the signals were studied via a partially implemented python Jupyter Notebook working on the PLAID dataset. In this notebook the students had to implement some functions in order to be able to load the data, visualize in time and frequency domains, and extract features from the signals. These functions had to be coded following a specified interface signature. In that way, the students could start to design the pieces of code that would be reused in the subsequent practical sessions.

A primary qualitative analysis of the discriminating power of the features was conducted by the students through box-plots as seen in figure 4. As shown in figure 5, single features as the fundamental power factor could help discriminate certain appliances [6]. A clustering analysis was also done to see sample distributions, and the intra and inter classes distances, considering different pairs of features, as in figure 5. With this simple graphical tools, the students could gain intuition on the features and their discriminating power.

B. Circuit design - 2019

The circuit design process included the implementation of the conditioning circuits for the voltage and current measurements. Taking into account that these circuits could be implemented with active approaches, the implementation of a DC power supply circuit was also necessary.

The specifications of the measuring circuits were given to the students and they were asked to study classical solutions to reduce and amplify voltages and to convert currents into tensions. It was also necessary to investigate possible strategies to improve the quality of measurements in noisy environments and to protect analog inputs of the ADC against surges.

After this investigation, the student groups devised their solutions that were afterwards discussed in class with the teachers. The final designs were simulated in the LTSpice software in order to assure the correct frequency response.

Once the designs were finished, the groups assembled the circuits on protoboards. The implementations were then surveyed using the Network tool of the WaveForms software and the frequency responses were compared to the previous simulations.

All this stage was performed with the junction box closed and only using the outputs from the 230 V/12 V transformer, the 230 V/5 V transformer and the output of the current clamp.

A more in depth description of this activity can be found in [6].

C. Circuit design - 2020 edition

Taking into account that the 2020 edition would miss the interaction in the lab, the decision was to give up the freedom in design of conditioning circuits and exchange it with a guided approach where students work on specific circuits a bit more complex.

Figures 6-7 show the proposed circuit architectures for the analog signal conditioning chains.

Figure 6 summarizes the conditioning circuits and the context in which they work including the junction box's top-level connections, the power line, the appliance, the AD2. The voltage conditioning circuit is expanded in figure 6,

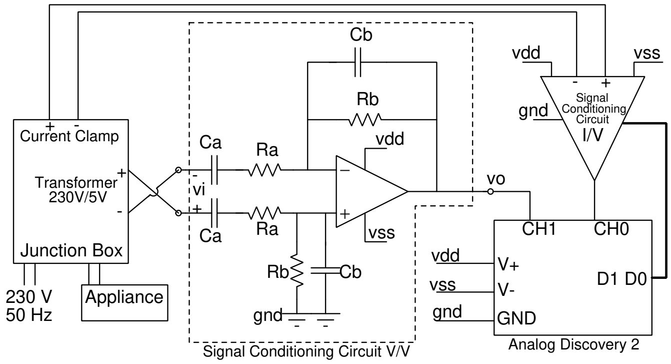

Fig. 6: Top-level connections of the junction box, including the power line, the appliance, the analog discovery 2, and the conditioning circuits. Proposed voltage signal conditioning circuit V/V is expanded (inside the dashed line box), where a differential structure was selected to cope with the differential-input and single-ended required conversion, along with the DC-decoupling and bandwidth limitation.

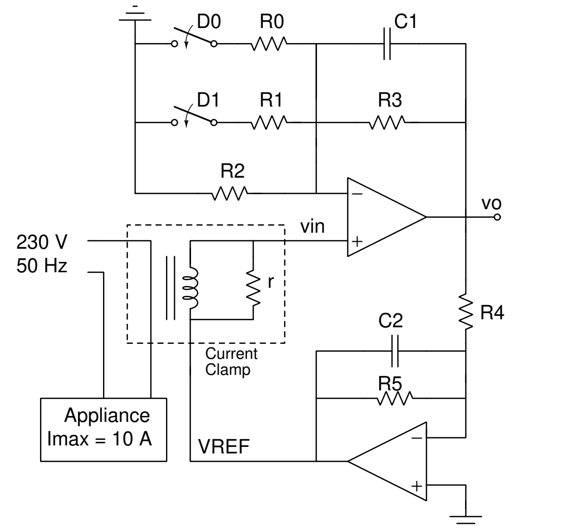

Fig. 7: Proposed signal conditioning circuit I/V used for the acquisition of appliance consumption. Such a load is sensed with the current clamp device, the resulted voltage (between vin-VREF nodes) is amplified by the proposed structure, which features programmable gain (values of 20dB, 40 dB, 60 dB to cope with the large loading ranges) and band-pass characteristics (to limit the signal bandwidth and reduce offsets effects at large gains).

whereas the current one in figure 7. The voltage conditioning circuit is based on a basic differential structure, featuring DC-decoupling and bandwidth limitation characteristics. The structure was comfortable for the students to cope with, mainly because the topology was previously studied at fundamental electronic courses. Nevertheless, the current conditioning circuit integrated a few new elements, which were interesting to be introduced in the workshop.

The inclusion of programmable gain characteristics in the current conditioning circuitry is one of the improvements for this workshop edition. As previously mentioned, large and small gains are required to deal with the low and high consumption appliances (respectively) by using the same piece of conditioning hardware. Three different gains are specified (20dB, 40 dB, 60 dB) to cope with the appliance's consumption ranges, ensuring the proper acquisition of the current signal. Additionally, the possibility of the gain being selected through the digital bus of the AD2 was another incorporated feature; it aims to choose the signal path gain by software, which offers a convenient feature mainly at appliance acquisition time. Further, it provides the hardware primitives to develop more automatic appliance acquisition procedures, which might be explored in future workshop editions. An analog switch integrated circuit (DG412) was included in the design as D1 and D0 in figure 7, which allows to commute the resistances and perform the gain selection digitally. However, the high gain signal path eventually may lead to large offsets, affecting the signal acquisition. Such a difficulty offered the opportunity to introduce the DC-attenuation-loop concept, which is an approach widely used in, but not limited to, the biomedical signal conditioning design [18]–[20]. DC-attenuation was defined by the feedback loop of R4, R5, and C2, along with the operational amplifier in figure 7. Despite the complexity of the presented conditioning circuit, the design exercise being introduced and faced in a modular approach allowed the students to achieve remarkable designs even with a minimal circuit design experience.

For the conditioning circuits, the design flow started with a phase of analysis to understand the circuit's topologies, followed by calculus to find the main design equations. The students put together design routines in order to achieve the requirements. Then, the designs were simulated in the LTSpice software in order to verify the specifications were achieved. As in the previous edition, the groups assembled the circuits on the breadboards for the hardware characterization. The Analog Discovery 2 was used for such testing along with the Scope and Network tools in the WaveForms software. A final manuscript reporting the complete design flow was the assignment for the groups of students. Figure 8 summarizes the results for one of these groups, where; frequency responses of the I/V-conditioning circuit are shown on top, simulation (left), and measurements (right) for the three designed programmable gains (20 dB, 40 dB, 60 dB). The resulting frequency response of the V/V-conditioning circuit, simulation vs. measurement, is superimposed at the bottom-left (Fig. 8). The temporal acquisitions from both signal paths are shown in Fig. 8 (bottom-right) when a laptop was connected to the junction box.

D. PCB design, printing and assembly - 2019 edition

For this phase of the workshop a tutorial on the design and constructions of PCBs was given to the students. The Eagle software [8] was used as an example of electronic design automation tool. Following the tutorial, the student groups developed the layouts of the circuits, as shown in figure 9.

Afterwards, the circuit layouts were printed on photographic paper and transferred by heat to a copper plate. The students had to inspect the transferred ink in the copper plates in order to detect and correct possible faults, specially cutted traces and missing pads. The plates were then introduced in iron

[8]https://www.autodesk.com/products/eagle/overview

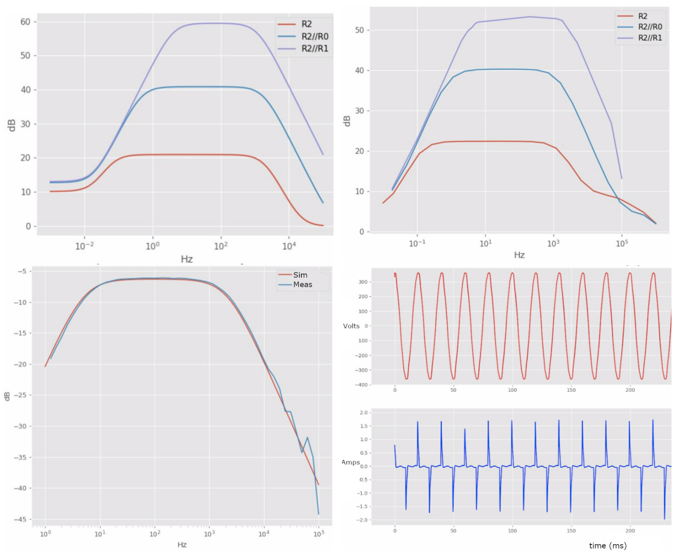

Fig. 8: Characterization of the conditioning circuits, simulation vs. measurements, and time acquisitions, reported for one of the student groups. Top: I/V-conditioning circuit simulation (left) and measurement (right). Bottom: V/V-conditioning circuit simulation vs. measurement (left), time acquisition of the relevant signals, voltage and current at the under test appliance (right)

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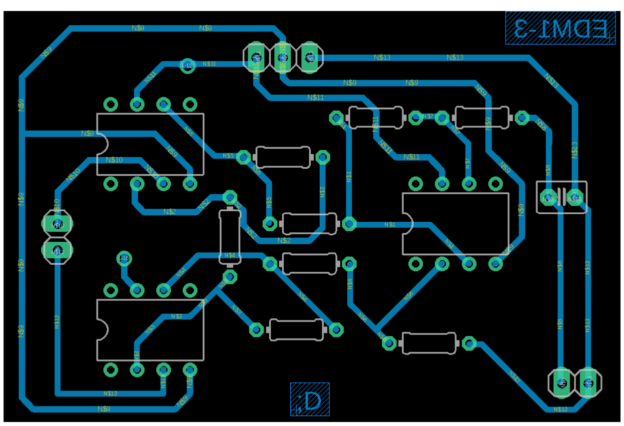

Fig. 9: PCB printed circuit board design (2019 edition)

perchloride to remove the exposed (not inked) copper. Finally the components were welded and the correct functioning was checked.

The conditioning circuits and the DC source were implemented in separate plates following the restrictions of size ($50mm \times 70mm$)

After verifying the correct operation of the PCBs, a protocol was proposed for the connection of the adaptation circuits to the junction box. This task was carried out under teachers supervision. The box was closed leaving as outputs only the cables corresponding to the conditioned signals to measure with the ADC.

Figure 10 shows the inside of the box after including the circuits designed and built by the students.

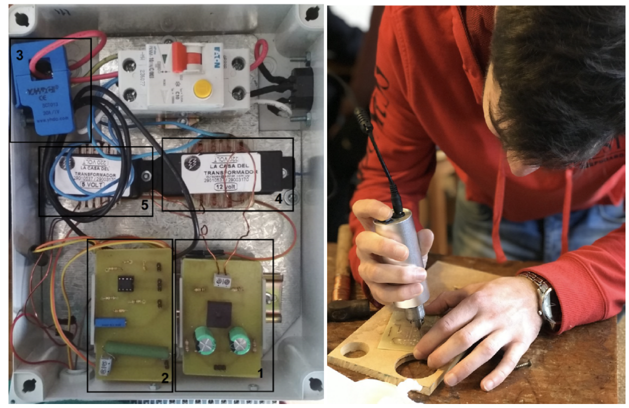

Fig. 10: 2019 edition. Left: Top view of the inside of the box including the PCBs designed by the students. Right: Drilling of a PCB by a student.

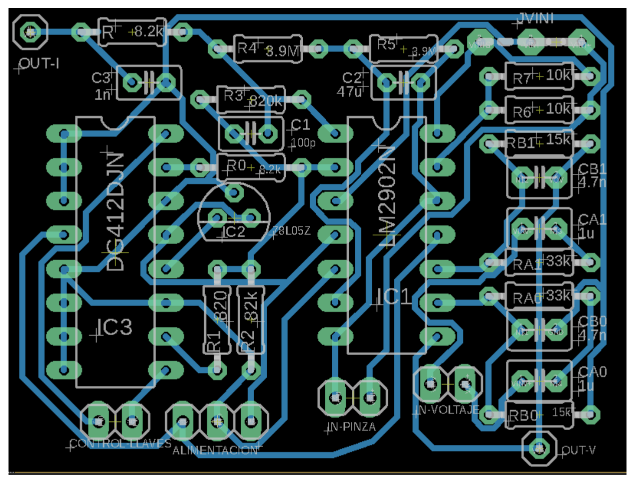

Fig. 11: PCB printed circuit board design (2020 edition)

E. PCB design and printing alternatives - 2020 edition

In the 2020 edition, an enhanced tutorial was given to the students before they started developing the layouts of the circuits. Also, the 50mm x70mm size specification for the 2019 edition was replaced by the objective of making the design with least area. As a result more compact designs were achieved. Figure 11 shows the result of the PCB design for one group with a size of 47mm x 36mm; the group sought the complete routing of the conditioning circuits in figures 6-7 by using the bottom layer only . Other designs using two layers achieved smaller areas down to 37mm x 37mm.

As mentioned before, the activity of manually printing and assembling of the PCBs was laid aside for this edition. Instead, the students were asked to investigate printing alternatives in the local and international market. The work was proposed as a collaborative task for all the students of the class sharing the information in a common forum and wiki. The comparison of alternatives had to take into account different variables such as prices, places, printing qualities, lead times, order quantities.

F. Calibration of the V and I measuring circuits - 2019 edition

The objective of this stage was to find end-to-end conversion constants for the voltage and current measuring circuits.

Calibration was performed under teacher supervision using the GW Instek APS-1102A2[9] programmable power supply. The calibration was performed only in amplitude, not in phase.

For the current measurement circuit, different resistive loads (0.1, 0.2, 0.5, 1, 2, 3, 5, 10 A) were acquired, the output voltage amplitudes were registered with the ADC and the estimation of the conversion constant ($K_i[A/V]$) that minimized mean square error was calculated.

For the voltage measurement circuit, several input voltages around the nominal voltage (207, 211, ..., 239 V) were tested with the programmable power supply, the output voltage amplitudes were registered with the ADC and the estimation of the conversion constant ($K_v[V/V]$) that minimized mean square error was calculated.

G. Classification

The introduction to supervised learning was done with a short tutorial and a partially implemented python Jupyter Notebook was proposed to the students. In this notebook the students had to explore different classification algorithms using the features computed in previous practical sessions. The PLAID dataset was used and a cross fold validation approach (leave one household out as in [15]) was used to estimate the mean accuracy. The students compared the accuracies for different set of features and for different algorithms, and parameters of the algorithms.

Best results on PLAID for the different groups of students are presented in table II. An interesting result is that, although similar base models (RF, K-NN) were used, the groups chose very diverse parameters and feature selections, and in most cases their results were close to those reported in the referenced works. It is worth adding that competing for the best performance in identification, generates extra motivation in experimenting with different classification strategies.

H. Assembly of the end-to-end solution

Once all the necessary building blocks have been studied, it is possible to build an end-to-end solution that yields a class or class probabilities given a connected appliance as depicted in figure 12.

The integrated solution allows the students to acquire data from different appliances and to test their classifiers.

In the 2019 edition the conditioning circuits were assembled in PCBs and placed in the junction box as shown in figure 10-left. This gave a “professional” finishing for the electronics with the ability to easily move the box to acquire signals in different locations. For the 2020 edition the circuits remained in protoboards making the solution less robust for acquisitions. On the other hand, the addition of programmable gains in 2020 is a remarkable feature that allows to acquire the signals of a wide range of appliances with a much better signal to noise ratio and avoiding quantification issues in the ADC.

[9]https://www.gwinstek.com/en-global/products/detail/APS-1102A

I. Dataset adquisition: IIE-v1 dataset - 2019 edition

With the boxes ready and closed, the student groups began the acquisition of different appliances in order to build a local dataset named IIE-v1.

The acquisitions were made at the faculty and at the student residences following an established protocol, in which the house, type of appliance, acquisition instance and the calibration constants corresponding to the box are identified. Similar to the PLAID dataset, the voltage and current are recorded for each instance in an off-on way during 4 seconds (the appliance is powered on at the begging of the recording). Taking into account that the local line frequency is 50 Hz, a sampling frequency of 25 kHz was selected, which allowed 500 samples to be obtained per cycle consistent with the PLAID dataset. For the IIE-v1 dataset more than 550 instances were acquired across 27 households.

J. Dataset adquisition: IIE-v2 dataset - 2020 edition

In 2020, the acquisition protocol was modified to include the automatic identification of the appropriate gain which lead to better conditioned signals.

K. Classification experiments with the IIE-v1 dataset

Through a Jupyter Notebook the students studied the classification on the IEE-v1 in two different scenarios:

1) Apply on the IIE-v1 dataset the classifiers trained on the PLAID dataset
2) Train on the IIE-v1 dataset

In the first scenario, the students could see significant performance degradation. Beyond the performance values obtained, it was considered that going through this process allowed to introduce and discuss basic concepts of machine learning. For example, the students could see that some of the models with best performance on PLAID did not work so well on IIE-v1, and this allowed to talk about generalization error.

Results were better but also low in the second scenario, as shown in figure 13. This led to the exploration of the possible causes of the low performance. The analysis of the signals of the IIE-v1 dataset showed that not all the groups had followed the same procedures and in some cases the signals were of bad quality probably due to faulty cable assemblies.

Overall, considering that all the acquisitions were done at the end of the workshop in a limited period of a week, the IIE-v1 dataset construction is considered a valuable experience for future acquisition campaigns.

L. Final report and presentation

On the last week of the workshop, the student groups compiled a final report in IEEE article format. A suggested layout was proposed to the students in order to guide them to the typical structure of research papers. It was for them a real challenge to compress all the design criteria, the experiments and results in a limited space article.

To conclude the workshop the results of the groups were exposed in oral presentations. Since the problem was the same for all the groups the presentations concentrated on

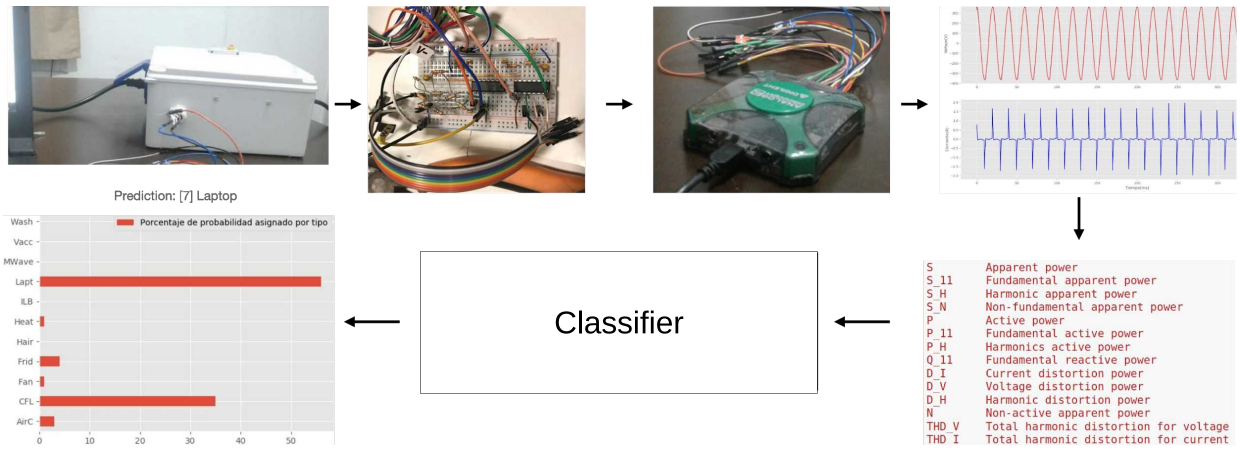

Fig. 12: Block diagram of the end-to-end solution. The voltage signals proportional to the current and voltage on the appliance are output from the junction-box. The circuits designed and implemented by the students adapt these voltages so that they can be acquired with the AD2. Features are extracted from the acquired signals and fed to a previously trained classifier. Finally the classifier yields the class probabilities for the connected appliance.

the particular design decisions and results of the groups. It was a fruitful event where the different strategies were put in common for all the participants of the workshop.

M. Assesment

There are multiple instances of work assessment during the semester. The materials, slides and practical works are organized in a Moodle [10] platform as all the courses off the Electrical Enginnering degree. All the practical works require an upload of a Jupyter Notebook or a report to the moodle of the course.

Topics related with signal processing and machine learning are introduced and evaluated through Jupyter Notebooks where the students must complete code, devise and perform experiments, and answer specific questions. Topics related to electronics and circuits require that the students write a report with their design decisions, simulation results and tests.

The uploaded material is evaluated by the teachers and discussed afterwards with the students in an oral defense. Although called a defense, this instance that takes between half an hour and an hour, is not only an assessment on the group and individual acquired knowledge but also an opportunity to give feedback of the uploaded work, openly discuss the topic concepts and clear eventual doubts.

At the end of the semester the groups write a report in article format that comprises all their work in the workshop. This is an instance where the groups have to see in perspective all their work during the semester and write it down concisely and with the correct format. Finally the student groups present their work in an oral session. In this instance the students must stand and deliver their main design decisions and achievements.

All these instances contribute to a close follow-up of the groups and the individual students. The final qualifications are derived as a weighted sum of all the results of these assessment instances.

[10]https://moodle.org/

Group	Selected features	Classifiers	Performance: Acc
EDM1-1	Features_IEEE[:,5:]	RF(n_estimators=85)	85.21
EDM1-2	Features_IEEE, IM-VI, IM_trans	RF(n_estimators=15)	83.78
EDM1-3	Features_IEEE, featuresVI, featuresTI, IMG_VI32	RF(n_estimators=400)	91.62
EDM2-1	Features_IEEE[1,3,4,5,6,7,9,12,13],FP_tot, FP_fun, IMG_VI	RF(n_estimators=100)	86.78
EDM2-2	P_11, Q_11, D_I, D_H, N, THD_I, IMG_VI	RF(n_estimators=800)	86.78
EDM2-3	IMG_VI width=23	RF(n_estimators=100)	77.42
EDM2-4	Features_IEEE, IMG_VI, IMG_trans, MaxI	RF(n_estimators=100)	85.56
EDM2-5	Features_IEEE normalized	KNN(n=8)	83.45

Tab. II: Identification results with PLAID dataset

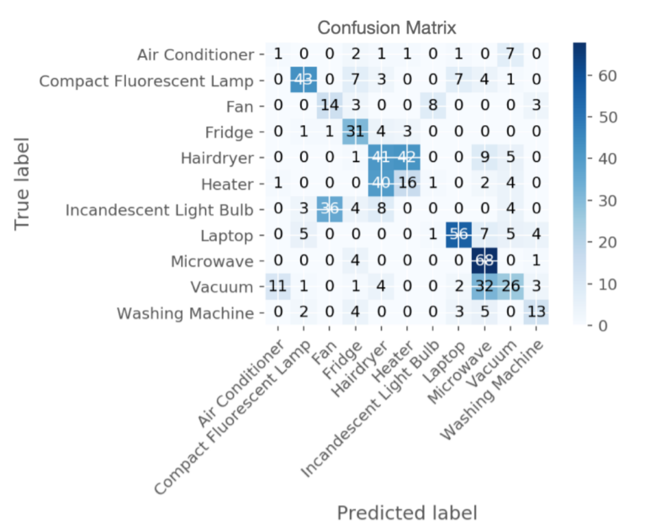

Fig. 13: Confusion Matrix obtained when training and classifying with the IIE-v.1 dataset

N. Evaluation of the course

At the end of the oral session that closes the course, an oral evaluation of the workshop is proposed to the students. They are encouraged to express the impressions on their experience in the course including positive and negative aspects, acquired knowledge, difficulties, time spent on the workshop, etc. This gives a preliminary feedback that is afterwards complemented by the anonymous written surveys carried out by the Teaching Department of the Faculty on the Moodle platform. The surveys included in 2020 specific questions related to the delivery of the courses in a non-classroom modality and the personal situation of the students in this context.

The evaluations for both editions presented a positive feedback from the students specially valuing the opportunity to put into practice different subjects of the degree in the frame of an interesting topic. The students reported a workload according in general to the design estimation with some overload in the programming tasks of the first weeks in Python, a new language for most of them.

V. Conclusions and Future Work

During the semester, the students are able to implement, in a guided way, an end-to-end solution that integrates the acquisition, processing and classification modules. This includes the hardware and software that allow to acquire the V and I signals of an appliance and predict its type. The workshop achieves the proposed goals, both in terms of integrating knowledge of previous and ongoing subjects, and also acquiring practical skills in software and hardware, teamwork, generation of technical reports and solving an end-to-end project in a limited time. The challenges tackled in the workshop, which are characteristic of an electrical engineering project, will help the students in facing the final degree project and also in future professional activity. Likewise, the workshop methodology and the challenges of the load monitoring problem allows the students to get closer to the scientific research process, reading reference papers, writing a report in paper format and doing oral presentation of the results.

Regarding the classification task, it allows the students to corroborate that they can get state-of-the-art results on a public dataset but this results can degrade when transferred to other data. This shows the difficulty of generalization, the need of retraining classifiers and the importance of carefully acquiring new data following a strict protocol.

As a byproduct of the workshop, devices are assembled which will be useful in future data acquisition campaigns necessary for the ongoing research line on NILM.

The pandemic scenario in 2020 imposed some adjustments but the main spirit of the workshop remained. The course, developed in the second semester of 2020, was carried in a context of social distancing and non-classroom teaching. In this period the country sanitary situation allowed the students to work in groups and share equipment with the necessary personal responsible measures. With a more restricted situation it would have been more complicated and more equipment would have been required to work individually. The ubiquitous availability of internet infrastructure in the country also enabled that all the actors could join the classes from any location.

Although the difficulties imposed by the pandemic, the students could fulfil all the required activities even when all the electronics assembly and testing had to be done at home. The social distancing limitation required a more thorough planing of the workshop with the anticipation of purchases of components that had to be done by teachers and students. A basic kit of components, difficult to purchase in the local market, was previously imported and given to the students at the beginning of the workshop. The rest of the electronic components, following the design, were bought by the students in the local market but the activities were planned with the intention to minimize the visits to the electronic stores.

The success of the 2020 edition showed the importance and usefulness of USB oscilloscopes such as the AD2 that enable the students to have a mini-lab at home with the integrated functionalities of power source, signal generator, oscilloscope and digital inputs/outputs. These devices, purchased originally to be used in occasional home activities, were crucial for the development in 2020 of the workshop but also of many other courses helping to carry on with electrical engineering degree in this challenging scenario.

Many changes and adaptations required to cope with the pandemic situation can be regarded as learned lessons and new opportunities to improve the teaching for future editions of the workshop and the electrical engineering degree in general. The better planing and routinely recording of classes, new hands-on activities that the students can carry on by their own with available enabling equipment, the possibility of interaction with students scattered all along the country are some of the improvements that we shall continue and extend when normal conditions are finally reestablished.

Hands-on integrative workshops with teachers and students working several hours together in an ambience of camaraderie allows an horizontal exchange of information, among students and between students and teachers. Topics about studying Electrical Engineering are shared, students ask about the degree and other courses, teachers share experiences about research in the area and professional life applications, etc. In short, information and experiences are socialized in the group. This exchanges increase student's engagement with the degree, which ultimately translates into better academic results. However, we have noticed from the experience of 2020 that this communications does not occur naturally in a context of social distancing. During the workshop, the interaction during conference calls, even in breakout rooms, tend to concentrate on the specific topics of the practical sessions and more general discussions are less frequent. We strongly believe that this issue should be analyzed and that the construction of human relationships is something to seriously consider when evaluating the costs and benefits of non-classroom distant teaching/learning.

For future editions of the workshop some variants could be included:

1) The exploration of other types of circuits such as using the digital bus of the AD2 to provide more automatic features at acquisition time, i.e. to capture signal transients.

2) An introduction to IoT, transmission of data to a central repository, apps for online data visualization and statistics
3) Considering the long-term fingerprints of the appliances,
4) Tackle the dissagregation problem

As a closing remark, it is worth to say that the workshop received positive feedback from the students including enthusiastic comments on how it had sparked their interest in previously unconsidered career areas and in doing research. This constitutes an important stimulus for the development of the future versions of the workshop. The 2020 experience showed that it was possible to develop the workshop in a context of non-classroom teaching. Although this is not the best alternative for a hands-on course, the experience makes us confident to face future editions in the frame of a sanitary situation that is still uncertain.

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Finally, authors want to highlight the enthusiastic participation of the students during the workshops.

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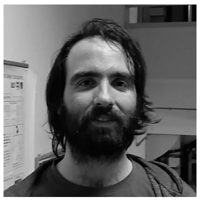

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