Household Appliances Identification: An integrative workshop for the Electrical Engineering degree

Alvaro Gómez, Pablo Massaferro, Camilo Mariño, Ignacio Irigaray, Andrés Cardozo and Alicia Fernández

Instituto de Ingeniería Eléctrica, Facultad de Ingeniería - Universidad de la República

{agomez, pmassaferro, cmarino, irigaray, acardozo, alicia}@fing.edu.uy

***Abstract*—In the Electrical Engineering degree , the integration of theoretical and practical knowledge is essential. Throughout the degree , there must be instances where the students can face specific problems and test their learning. With this in mind, 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 problem of the identification of household appliances from consumption records presents multiple challenges suitable to develop all the desired skills and also for the initiation to research.**

***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. This activity confirmed the relevance of hands-on subjects, which not only generate specific learning but also life 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 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 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

[1] Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República, Uruguay

978-1-7281-6732-9/20/$31.00 ©2020 IEEE

results are exposed in section IV. 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. 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]–[5] A complete review of disaggregation techniques until 2016 can be found in [3] and more recently in [6], [7].

A simpler problem is the identification of an appliance when only one is monitored at a time. This is addressed for example in [8], [9] as a supervised problem. The workshop presented in this article focuses on this problem.

For the sake of completeness, an extended literature review on load monitoring is presented in the rest of this section. This review is not indispensable for the understanding of the article and can be skipped by the reader if desired.

A. Literature review on load monitoring

First NILM studies began in 1985 with the work of Hart [10], focused on the detection and characterization of events under the hypothesis that a variation in the consumed active power is due to a change on the status of an appliance.

Several NILM algorithms based on HMM (Hidden Markov Model) for the disaggregation of energy at a low sampling rate, have been proposed [11]–[14]

More recently, the availability of larger databases has allowed addressing the problem using deep learning techniques and architectures. In 2015, Kelly and Knottenbelt [5] adapted three neural network architectures to the household appliance disaggregation problem: Long Short Term Memory recurrent neural networks (LSTM), Denoising Autoencoders and a combination of convolution and fully connected layers. This last approach, seeks to train a network identifying equipment activation rectangles (start, duration and height is the average power consumed). The UK-DALE [15] database was used to compare this work with the algorithms included in the NILMTK toolkit [16].

Reviews on dissagregation techniques can be found in [3], [6], [7].

Also related to NILM but simpler than dissagregation is the problem of identifying a single appliance from its electrical footprint. This problem is addressed in [8], [9] with a supervised approach. In particular, in [8] the detection of new devices that were not part of the training set is tackled. An unsupervised approach is carried out with the DBSCAN clustering technique in [17]. The feature space used for this analysis is generated by training a Siamese convolution network with binary images of V-I curves. The results tested on the PLAID [18] and Whited [19] databases show that, although the index of uncertainty is high on equipment of similar characteristics, the correct result is in the top 3 of suggestions (over 11 types).

An exhaustive comparison of different classification techniques, such as k-Nearest-Neighbors (kNN), Gaussian Naive Bayes (GNB), Logistic Regression Classifier (LGC), Support Vector Machines (SVM), Linear / Quadratic Discriminant Analysis (LDA / QDA), Decision Tree (DTree), Random Forest (RForest),Adaptive Boosting (AdaBoost), is done in [9] by the same research team that made the PLAID database. This work also tests different features that can be extracted from the voltage and current curves.

Regarding feature extraction or engineering of features, different proposals that are not reduced to the *active, reactive and apparent power* appliances consume are found in [18], [20]. Since Hart (1992) [21], other features including *harmonics* of the signal and descriptors of the transients were proposed.

One interesting feature, not only for its discriminating power for identifying distinct types of loads [22], [23], but also for the visual interpretabillity, is the *V-I path* [18], [20]. For example, resistive loads draw an almost straight line, while appliances with motors and switched sources show more complex trajectories. Figure 1 shows V-I images calculated from three instances of the PLAID dataset.

The *phase shift* between current and voltage is another important descriptor used.

In turn, there is a set of characteristics related to the representation of the frequency signal: the *distribution of energy in harmonics*, the *spectral flatness*, the *relationship between harmonics odd and even*, and other more complex relationships between the magnitude of the harmonics.

Other metrics such as the *Total Harmonic Distortion* (THD) and the *crest factor*, common in signal processing, were proposed in [24], [25].

Considering the transient, [26] introduced the *Inrush Current Ratio*, which relates the final and initial RMS of the current signal in the range of interest.

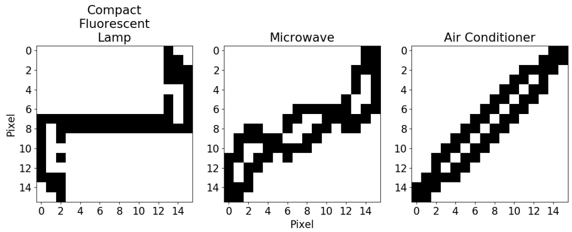

Fig. 1: V-I images of household appliances in the PLAID dataset [18]. The current vs. voltage diagrams are encoded as 16×16 pixel images

To end this section a brief review of non-intrusive monitoring products and services offered in the market is presented. An extensive but not exhaustive list can be found in the European NILM Workshop [2]. Information for contract terms options, security reasons, savings in real time recommendations are some of the benefits offered by providers.

Some products, such as Wi-beee [3], carry out consumption monitoring by reporting the data in real time, so that the consumer can visualize data on the load curve and can configure alarms, that allow her to control the monthly expenditure, this type of equipment does not include disaggregation algorithms.

Smappee [4] or Mirubee [5], for example, focus on cost reduction, looking to control the accumulated consumption of different appliances, while other companies focus on controlling home activities like Sense [6] or Watty [7] .

Depending on the objective, system requirements may differ. Identifying real time consumption is quite different from generating consumption summary, according to appliances category.

In general, the products have their own hardware, easy to install, and sense voltage and current at the entrance of electrical energy into the home. Part of the processing is done locally and part in the cloud.

Other companies, such as EEme (startup currently part of Uplight [8]) and Bidgely [9], offer consumption separation services, using information from smart-meters of distribution companies instead of specific hardware. The PecanStreet [10] company carried out an independent evaluation of EEme load separation system, on data acquired every 15 minutes [27] and every 1 second [28]. In the first case, it is shown that the absolute monthly identification errors are greater than 30 %, reaching up to 45 % in the clothes dryers, while when the acquisition rate is lowered to the second and the average error is measured by hour per application, these are less than 10 %. This shows that NILM is still a challenging problem not only for the academy but also for the industry.

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 [18] 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 with the participation of 27 students in 8 groups [11]. The teaching was carried out by a mixture of teachers from the Signal Processing and the Electrical Power departments [12]. The students were also from several different profiles within the EE 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.

[2]http://wiki.nilm.eu/companies.html
[3]http://wibeee.circutor.com/
[4]https://www.smappee.com/eu_es/homepage
[5]https://www.mirubee.com/
[6]https://sense.com/
[7]https://watty.io/
[8]https://uplight.com/
[9]https://www.bidgely.com/
[10]https://www.pecanstreet.org/

[11]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

[12]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)

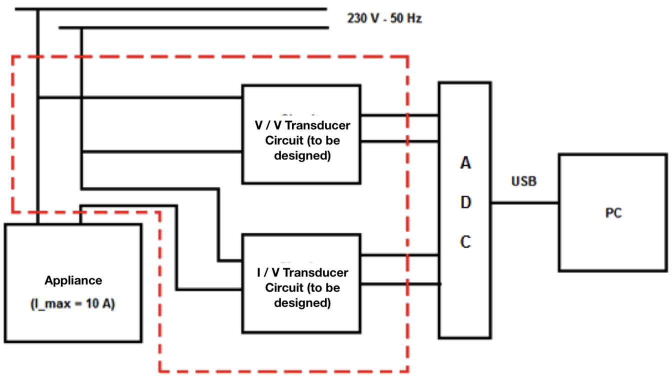

Fig. 2: Block diagram of the proposed solution.

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 red 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 [29] 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[13] [18] 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.

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], [18], 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 figures 3 and 4.

For the acquisition of the signals, the Analog Discovery 2 (AD2), an all-in-one USB oscilloscope and instrumentation system from Analog Devices[14], is used, as the analog to digital

[13]http://www.plaidplug.com/
[14]https://analogdiscovery.com/

Fig. 3: Junction box for mounting measurement electronic circuits. It remains closed with 4 fixing screws whenever it is connected to electricity

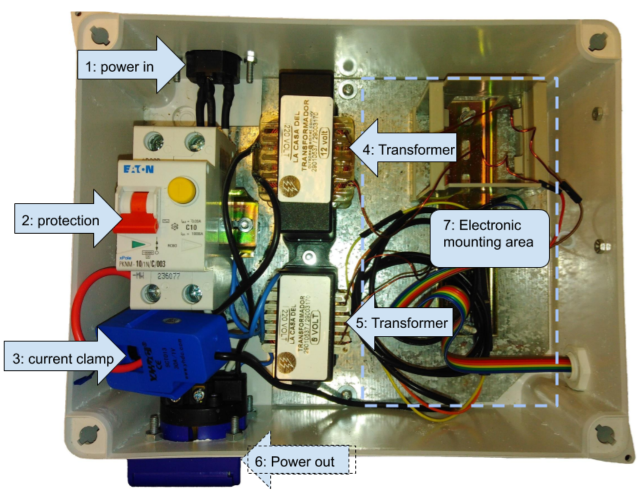

Fig. 4: Inside of the junction box: 1) IEC C14 10A power connector, 2) differential magnetothermal circuit breaker 30mA/10A, 3) Split core current transformer SCT-013-030 30A/1V , 4) Transformer 220V/12V 10VA, 5) Transformer 220V/5V, 6) schuko socket outlet with hinged lid, 7) Din rail and mounting area

converter. It has a voltage range of ± 25 V and a resolution of 14 bit.

The WaveForms [15] 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, as shown in Figure 5.

Designed circuits are simulated with the LTSpice[16] 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.

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

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

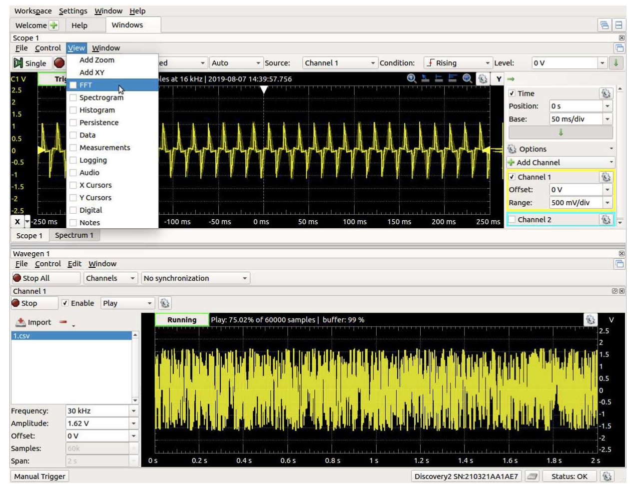

Fig. 5: Signal analysis and visualization with WaveForms.

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.

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.

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) Acquisition and analysis of signals with the AD2. Use of the WaveForms software.

A.4) Design of conditioning circuits. Study of alternatives and selection of a solution. Simulation of circuits in LTSpice[17] software. 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.

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

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.

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

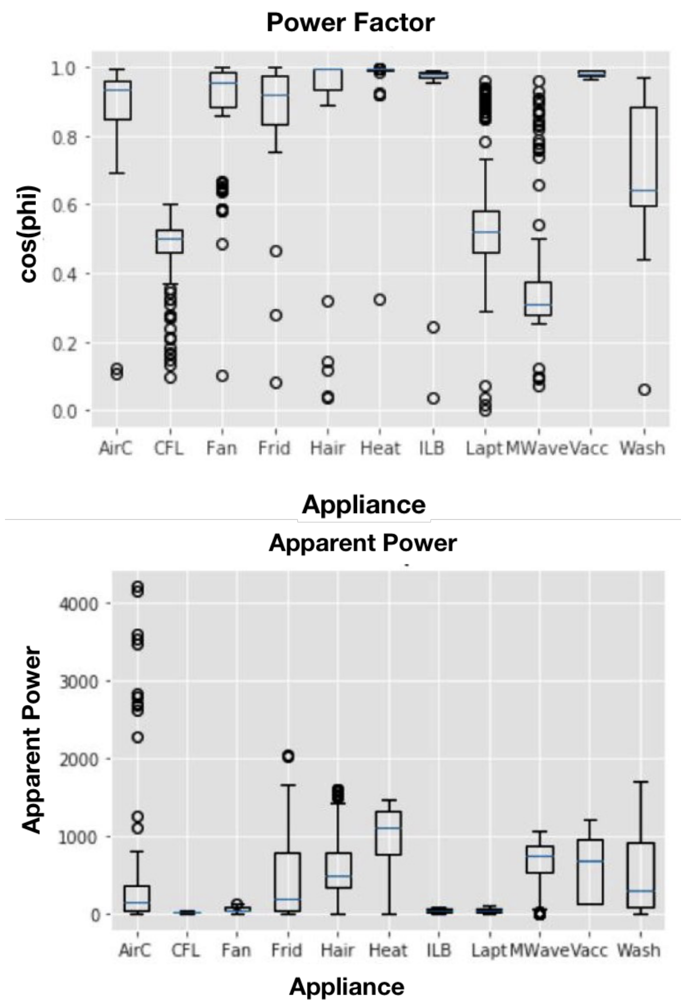

Fig. 6: Box plots for the analysis of different features

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 shown in figure 6, single features as the fundamental power factor or the apparent power could help discriminate certain appliances. Similarly, 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 7. With this simple graphical tools, the students could gain intuition on the features and their discriminating power.

B. Circuit design

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. A schematic of the proposed DC source circuit is shown in figure 8.

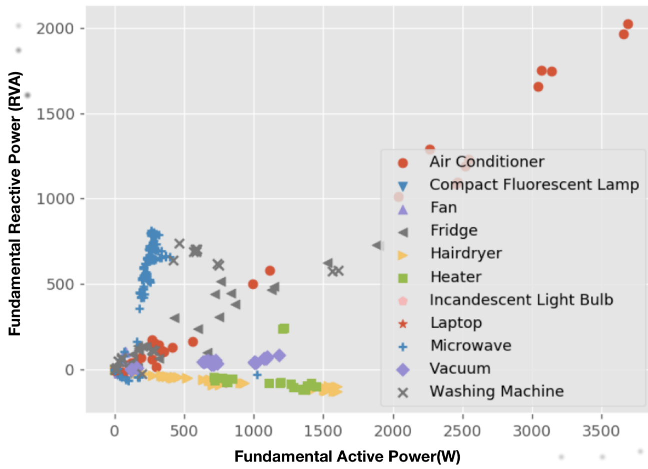

Fig. 7: Clusters in the fundamental active vs reactive power plane

Voltage transducer circuit	Current transducer circuit
Input: 230 V -10 % + 6 % @ 50 Hz	Input: 40mA - 10A / 50Hz - 2kHz
Output: to be defined, taking into account the permissible voltage values and resolution of the ADC	Output: to be defined, taking into account the permissible voltage values and resolution of the ADC
Error in the transduction: constant @ 50 Hz: less than 2 %	Error in the transduction constant @ 50 Hz: less than 1 %
Phase error: less than 100 '	Bandwidth: 2 kHz

Tab. II: Specifications for the conditioning circuits design

The specifications for the conditioning circuits are shown in table II.

Defined the requirements and restrictions for the design of the measurement circuits, it was proposed to the students, as a starting point, 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.

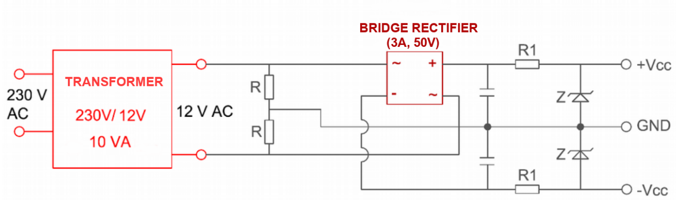

Fig. 8: DC source to power the conditioning circuits.

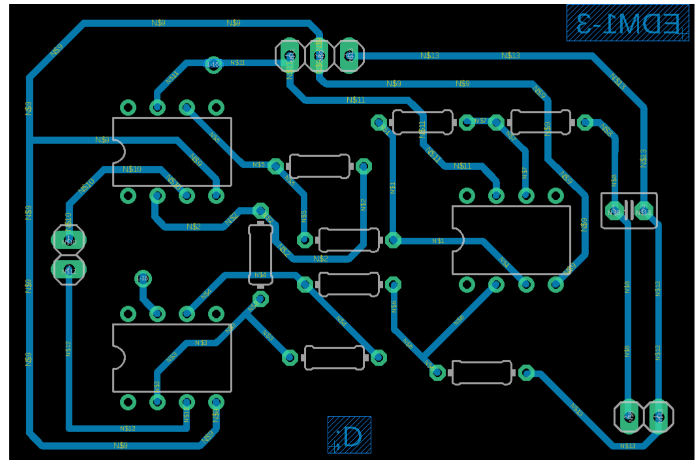

Fig. 9: PCB printed circuit board design

C. PCB design, printing and assembly

For this phase of the workshop a tutorial on the design and constructions of PCBs was given to the students. The Eagle software [18] 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 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.

D. Calibration of the V and I measuring circuits

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[19] 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

[18] https://www.autodesk.com/products/eagle/overview
[19] https://www.gwinstek.com/en-global/products/detail/APS-1102A

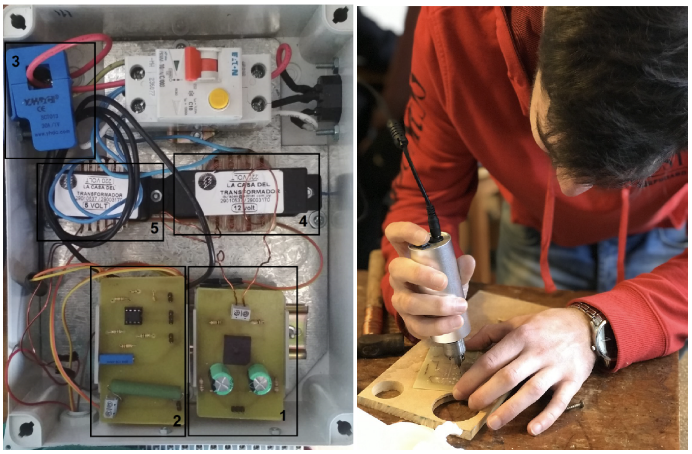

Fig. 10: Left: Top view of the inside of the box including the PCBs design by the students. Right: Drilling of a PCB by a student.

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.

E. 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 [18]) 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 III. 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.

F. Dataset adquisition: IIE-v1 dataset

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.

G. 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 11. 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.

H. 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 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.

I. Assesment

There are multiple instances of work assessment during the semester. The materials, slides and practical works are organized in a Moodle [20] 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

[20] 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. III: Identification results with PLAID dataset

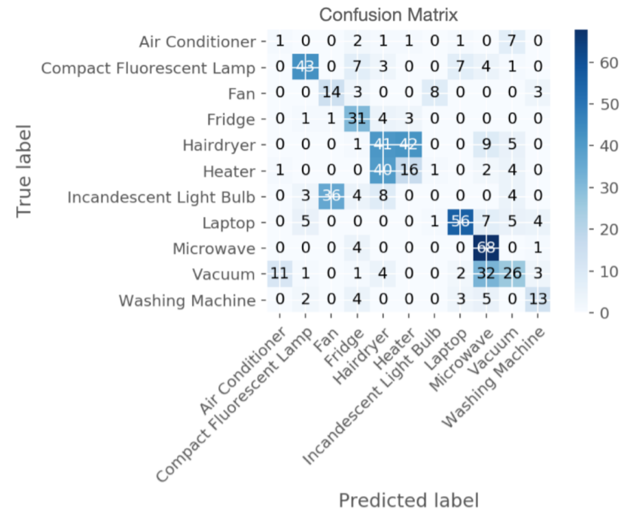

Fig. 11: Confusion Matrix obtained when training and classifying with the IIE-v.1 dataset

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.

V. Conclusions and Future Work

During the semester, the students were 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 achieved 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 allowed 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 allowed the students to corroborate that they could get state-of-the-art results on a public dataset but this results could degrade when transferred to other data. This showed 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, eight devices were assembled which will be useful in future data acquisition campaigns necessary for the ongoing research line on NILM.

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

1) The exploration of other types of circuits,
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.

Acknowledgment

The authors thank UTE for research support and for sharing their expertise. In particular, authors greatly acknowledge engineers Juan Pablo Maggi and Luis Pérez from UTE. Also CSIC for organizing ”Jornadas UTE-UdelaR”. The participation of Martín Avas and Santiago Machado in the implementation and dictation of the workshop and the support of Germán Fierro on electronic design, simulation and printing is especially appreciated. Alvaro Giusto supported this workshop and shared his experience on Tallerine. Elias Masquil and Franco

Marchesoni who along with Camilo Mariño carry out their final degree project on NILM contributed to the review of the state of the art. The IIE electrical/mechanical workshop officials Roberto Rodríguez and Sergio Beheregaray helped build the junction boxes. Finally, authors want to highlight the enthusiastic participation of the students during the workshop.

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