

Exploring the usability of a remote laboratory for photovoltaic systems

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Abstract: In engineering, remote laboratories present a triple role: they provide to the students the necessary contact with real devices, introduce them in the use of new technologies and make possible that the students conduct lab classes when and where they want. In this paper we present a remote lab devoted to photovoltaic power. The experimental system consists of two photovoltaic panels connected to a variable load and illuminated by a variable luminary. It allows the students to obtain different characteristic curves. The user interface has been integrated in Moodle. The system access management is carried out by software developed by authors. A didactic valuation process has been carried out to establish the acceptance of the educational experience by the students and to identify underlying factors. The hardware and software developed for this remote lab are not specific, but reusable for other remote lab experiences besides the one presented here.

Keywords: Engineering education, Remote lab, Photovoltaic System, Lab class, Pedagogical analysis.

1. INTRODUCTION

Practical training is an unavoidable part of scientific and technical studies. These classes have traditionally been taught in the laboratory. Their physical realization has several advantages. Mainly, the students take contact with the devices that they will handle in their professional development. In addition, it allows them to learn their real behaviour. In the last years, remote laboratory projects have been proposed. The aim is to teach fundamental concepts in different engineering fields through the remote operation and to control specific experimental facilities. Different activities towards the development of virtual and remote laboratory systems, (Andújar and Mateo 2012), (Gomes and Bogosyan 2009), are carried out by many academic institutions they cover several engineering fields ranging from electronics, (Sousa et al. 2010), (Andújar et al. 2011), to the automatic, (Santana et al. 2013). Focusing on photovoltaic systems, there are multiple papers about remote transmission systems to monitor them, (Bagnasco et al. 2012), (Naeem et al. 2011), among others.

Within the educational area, and focused on photovoltaic systems, virtual labs, (Drigas et al. 2005), are more extended than remote labs, (Thomsen et al. 2010), (Schauer et al. 2012), (Freeman et al. 2012), (Assante and Tronconi 2015). Among this last kind of labs, in (Thomsen et al. 2010) a photovoltaic remote system is presented as a part of another one which is composed of some other physical experiments. In addition, in (Schauer et al. 2012) authors propose the characterization of a solid state photovoltaic cell using several photovoltaic systems. In (Freeman et al. 2012) a

remote experiment is presented based on photovoltaic panels which makes possible that the student turns on and off a number of light bulbs, adjusts the load voltage by the photovoltaic panel and follows the experiment evolution in real time via web-cam. Another experiment based on photovoltaic system is presented in (Assante and Tronconi 2015). However, in this case its remote access is still in development.

Regarding the learning planning, one of the first experiments proposed to the students in courses about photovoltaic energy is the determination of modules characteristic curves and the effect of the meteorological conditions on them.

In this paper, a remote experimental system is presented, constituted by two photovoltaic modules connected to a variable load and lighted by a variable focus. It allows the students to obtain different characteristic curves and compare them. For example: curves with several irradiations and curves corresponding to one and/or two modules connected in different ways (serial and parallel). In this case, the student is an active element of the class. He or she takes the data, analyses them and draws the corresponding conclusions.

Regarding technical issues, to develop the remote lab presented in this paper, the innovative instruments related below were designed. All of them will be explained in the corresponding section.

- The use of Arduino board to control a high power luminary. Arduino, (Arduino 2015), is an open-source platform used for building electronics projects. Arduino consists of both a physical

programmable circuit board and an integrated development environment (a simplified version of C++) that runs on the computer.

- The use of Easy Java Simulation (EJS), (Esquembre 2015), to design the lab class experiment and its integration in a Learning Management System (LMS).
- The use of Augmented Reality (AR) techniques to improve the interface, (Mejías and Andújar 2012).
- The use of Modbus, (ModBus 2015), to unify the communications among all the components of the experimental system.
- The use of the Remote Access Service for Labs (SARLAB) as the system of access management. It is a communications software developed for this purpose.
- The use of a Raspberry Pi board (a low cost and small computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse), (RaspBerry Pi 2015) to optimize the energy consumption of the laboratory. This is not energized until a remote user wishes to use. Until then all its elements are off.
- Finally, a very important characteristic of the developed remote lab is that all hardware and software elements are open-source, so its setting-up and maintenance are low cost.

Within pedagogical framework, there are several papers in the Literature which have treated the analysis of usability of remote laboratories in University, (Casini et al. 2014), (Kulkarni and Jhunjhunwala 2013), (Tsiatsos et al. 2014). However, none of them have explored the dimensions underlying to the usability variable and its relation to the perception of usefulness by students. The identification of those factors in the design of remote labs will allow its acceptance by educative communities.

The paper is organized as follows: in section 2, the need for promoting the capabilities developed by the lab class in the Energy Engineering Degree is explained; in section 3, the designed lab class is presented and in section 4 the structure of the developed remote lab. In section 5, results of the analysis obtained are shown. In Section 6, the discussion of the usability is made. Finally, in section 7, some conclusions are drawn.

2. THE LAB-CLASS INTEGRATION IN THE SUBJECT

The behaviour of a photovoltaic panel is characterized by a curve which presents current versus voltage (V-I), Figure 1.

The remote lab is proposed as an instrument to improve the student knowledge of photovoltaic systems and, specifically, of the behaviour of the panels in real environmental conditions (mainly irradiance) when they are connected to

other panels and to different loads as happens in the real world. In addition, the student increases their skills on connecting photovoltaic facilities, carrying out electrical measurements and analysing them. The proposed remote lab class is also carried out in classroom labs with the same objectives. However, the remote lab provides the ability to carry out the experiment whenever and wherever the student wants.

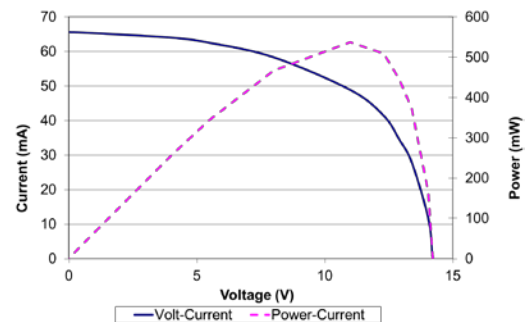


Figure 1. Photovoltaic module characteristic curve.

The lab class has been proposed to be conducted by the students enrolled in the Photovoltaic Solar Facilities. This is a compulsory subject, taught in the second course of the Energy Engineering Degree at the University of Huelva. The considered lab class is one of the first practical exercises proposed. In fact, the student must know the panel behaviour before boarding the photovoltaic facilities world.

Previously to make the proposed experiment, the student must know the photovoltaic panels and their theoretical behaviour. In addition, the teacher supplies to the student by means of the LMS a guide of the experiment.

3. LAB CLASS DEVELOPMENT

The developed user interface is shown in figure 2. It is composed of two parts. In the first one, in the top, the video image can be seen. It shows two photovoltaic panels lighted by a variable luminary, whose intensity is also shown by the camera image. However, the load presented in the image is not the actual one but it has been developed with AR technics as well as the panels connection in each case. Voltmeter and ammeter have also been included as AR elements in the user interface.

The second part of the user interface is constituted by the controls of the parameters that the users have to manipulate to conduct the remote lab class. They must regulate the luminary power (irradiance on the panels), item A in figure 2; load value, item B in figure 2; and panels connection, item C in figure 2.

Thus, for each light condition (irradiance condition) and each panels connection, students must change the load resistance value and taking notes of voltage and current in the load. They must keep all data in a datasheet to graph them as the lab class guide proposes: they must make one graph for each connection with all the curves corresponding to it (one for each light condition). These graphs will show to the students

the effect of the environmental conditions in the panels behaviour. The student must also make one graph for each irradiance condition. Each graph will be composed of one curve corresponding to each panel connection. These graphs will show to the students the effect of the different panels connection on their behaviour. In series connection voltages are added and in parallel, currents are added.

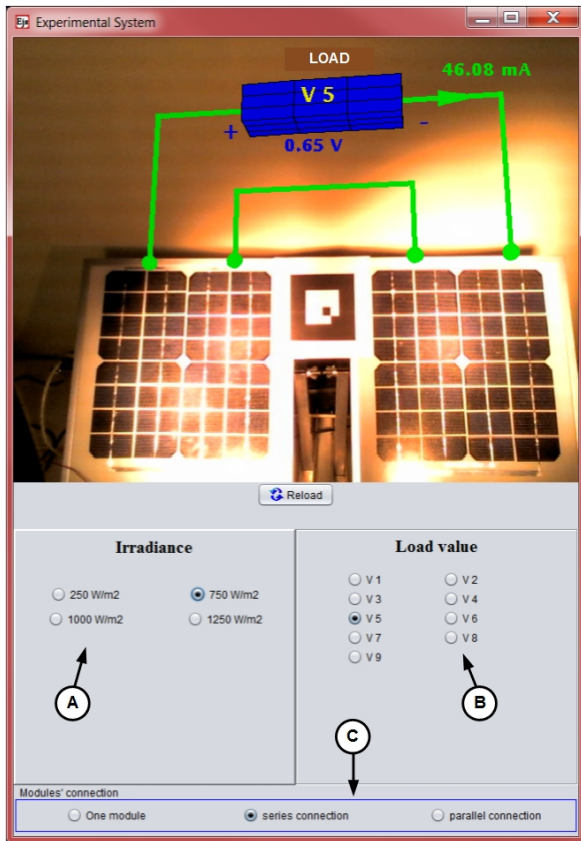


Figure 2. User interface.

4. DEVELOPED REMOTE LABORATORY

The proposed remote lab class in this paper has classically been taught in the classroom lab. The students manually switched on/off several luminaries to simulate the variation of the solar irradiance, as well as changed the position of a variable resistor (as load) to set the different work points of the photovoltaic panels. Furthermore, the panels connection was also manually configured.

All these manual actions required to carry out the lab class make necessary the same number of automatic systems to carry it out in remote way.

In the case of the remote lab proposed in this paper, the need for energy has been optimized by means of a Raspberry Pi board. This switches the system on when an user requires it and switches it off when the user finishes the work. In this same way of using open access devices, the I/O boards are Arduino. They are used to control the light power (variable irradiance on the panels) and the variable load and to measure the sensed parameters.

Regarding the light power that replaces the sun light, it must be controlled by the corresponding circuit connected to an Arduino board. In addition, the variable load must be controlled. It has also been made by another circuit connected to another Arduino board. There is a last circuit to change the connections (series or parallel) of the photovoltaic panels.

Besides the above, the experiment must be accessible from Internet to allow the lab class to be carried out in a remote way. Thus, the modification of setup and working points must be accessible from a TCP/IP network. To unify the method of accessing to these devices through the net, the standard Modbus serial communications protocol has been used. Modbus makes possible sending and receiving data between all the involved devices. In order to achieve it, different devices in the lab are monitored by an EJS element with Modbus master architecture. In the same way, a Modbus slave must be included in all the Arduino boards.

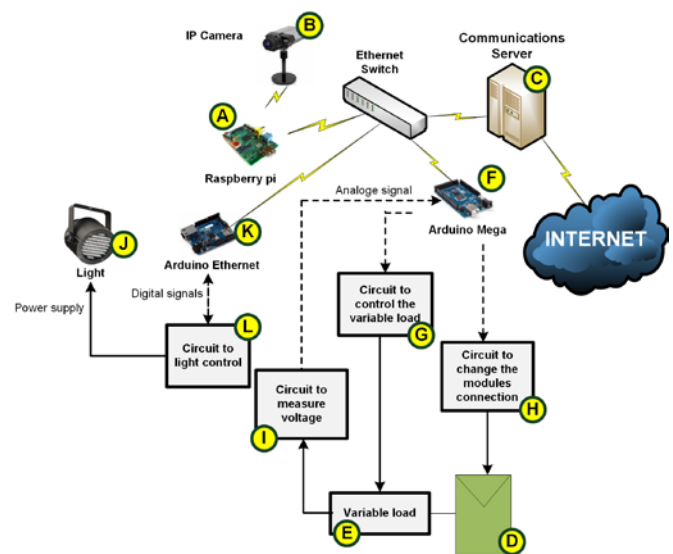


Figure 3. Diagram of the experimental system.

In figure 3, a general diagram of the developed remote lab is shown. As already mentioned a Raspberry Pi board, item A in figure 3, is used to remote control the switch on/off of the system and to optimize the need for energy. An USB camera, item B in figure 3, connected to the Raspberry, takes the video signal from the laboratory. After the user has accessed to the remote lab with the corresponding reservation, the camera sends the video signal to the user interface.

A communications server, item C in figure 3, is connected to the laboratory intranet as well as to the University corporate network by means of SARLAB. This server guarantees the links necessary for the communication between the students' computers and the photovoltaic system located in the remote laboratory. This software provides, automatically, the necessary connections based on the reservations made by the students and on the experiment connection specifications. In this way, the secure access to the laboratory resources and their proper use is ensured.

The core of the experimental system is the set of two photovoltaic panels, item D in figure 3. The nominal values

of each panel are 0.4 W and 12 V. They are connected to a variable load, item E in figure 3, which is controlled by an Arduino board, item F in figure 3, by means of the corresponding circuit, item H in figure 3. This board is also the responsible of configuring the panels connection (one only panel connected to the load, the two in series or in parallel), through the circuit marked as item I in figure 3. The last function of the board F is measuring the load voltage, through the corresponding circuit, item H in figure 3. The voltage measured is duplicated because there are two ranges to measure.

To illuminate the panels in order that they produce electrical energy, two lamps of 500 W are used, item J in figure 3. And to study the effect of irradiance in the characteristic curve of the photovoltaic panels, the power of the lamps is controlled through an Arduino Ethernet board, item K in figure 3. The control of a high power element by means of an Arduino board is possible thanks to a novel circuit developed by the authors, item L in figure 3. It is basically composed of two devices. The first one detects the zero value of the network electrical signal and the second one establishes, from this value, the set point to control the time of the period in which the lamp is on and off.

An user interface developed within EJS makes the experiment available for student. AR techniques have been used to improve the camera image. This interface has been integrated in Moodle, which is used in this case as Learning Management System (LMS). The experiment is available for

students 24 hours a day, 365 days a year, by means of a reservation system, also integrated in the LMS.

5. USABILITY AND EDUCATIONAL USEFULNESS

As already mentioned, Photovoltaic Solar Facilities is a compulsory subject in the Energy Engineering degree at the University of Huelva. Innovating was the driving force behind this work. In order to show the contributions and capabilities of the proposed system, a pilot study was completed in the second semester of the academic year 2013–2014. The statistical study is based on an anonymous test which was completed by the students after passing the exam corresponding to the subject. It includes issues related to the remote lab features and its usefulness. Students were required to rate the questions on a 5-point Likert scale (1—strongly disagree and 5—strongly agree). The results of the analysis are presented from now on in terms of goals of this study.

5.1 *Identifying the way of students to perceive usability and usefulness of remote lab.*

In general, it can be said that the remote lab classes had a very good acceptance by the students. They were kindly surprised with it. In fact, some students expressed their interest on the design of other remote lab classes and even on new experimental systems to be used in some other subjects into their Degree.

Table 1. Usefulness of remote laboratory by the students

		AV	SD
Q 0	Your level on photovoltaic systems is high	2.78	0.79
Q 1	This lab work allows strengthening the theoretical concepts	4.15	0.69
Q 2	The remote lab work makes easier the theoretical-practice understanding	3.71	0.64
Q 3	The overall assessment of the remote lab is positive	4.24	0.73

Table 2. Usability perceived by students

		AV	SD
Q 4	The interface allows the exercise to be carried out in the same way as in the classroom lab	4.37	0.54
Q 5	The exercise can be carried out without the professor supervision	4.54	0.60
Q 6	The time available to complete the tests is enough	4.76	0.54
Q 7	The information available in LMS is suitable to perform the lab work	3.90	0.83
Q 8	The use of the interface is easy	3.80	0.87
Q 9	The access to the remote lab through the LMS is easy	4.02	0.79

The participation was very high. Students enrolled in the subject were 44 and 41 carried out the remote lab class. The remaining three left the studies at the beginning of the year. Thus, the students' motivation with the proposed lab class and with the remote labs in general was very high.

Teachers have also been kindly surprised with the participation of students in the proposed remote lab class. Some of them are already working including other elements in the remote lab.

Based on student answers, tables 1 and 2, they think their initial knowledge of photovoltaic systems was not very high (Q0; average value, AV = 2.78). It must be taken into account that this lab class is proposed as one of the first lab class in the subject. Regarding the learning procedure (Q1 and Q2), the users confirm, by means of high scores, that theoretical concepts are strengthened and improved by the use of the remote lab (AV = 4.15). And remote lab work makes easier the theoretical-practice understanding (AV = 3.71). In

general, the students consider that the remote lab is a positive innovation in the Photovoltaic Solar Facilities subject (Q3; AV = 4.24).

Regarding the performing of the experiment (Q4, Q5, Q6 and Q7), students think it can be carried out in the same way as in the classroom lab (AV = 4.37), although without the teacher supervision (AV = 4.54). In this sense, a great advantage of the remote over the classroom lab is drawn: the control by software substitutes the necessary teacher supervision to guaranty the correct use of lab devices. In addition, students consider that the time available to complete the tests is enough (AV = 4.76). However there is no agreement with respect to the suitability of instructions to perform the lab work (AV = 3.90; standard deviation, SD = 0.83).

Considering the aspects related to the user graphic interface, students consider that it is friendly and easy to use (Q8) and that the access to the remote lab is easy (Q9).

5.1 Exploring dimensions underlying to the usability and its relationship to the usefulness perceived by the students.

An exploratory factorial analysis is used through SPSS 19.0 (Statistical Package for the Social Sciences) to confirm the possible effects of underling dimensions on the acceptance of remote lab class enhanced with AR. Thus, it is useful to validate the identification of these dimensions for the pedagogical design of this kind of educational experiences. The analysis of the main components is used as the extraction method. According to the exploratory factorial analysis, auto-values higher than 1 are required. Thus, 3 dimensions, which explain the 71.25% of the variance, are obtained after the Quartimax rotation (Quartimax is the matrix shown in table 3).

The next factors are saturated by the next variables, table 3: a) dimension 1 (comprehension) is saturated by variables Q4 (-0.830) and Q7 (0.839); b) dimension 2 (autonomy) is saturated by variables Q5 (0.748) and Q6 (0.848); and c) the dimension 3 (easy of use) is saturated by the variables Q8 (0.678) and Q9 (0.845).

Tabla 3. Matrix of rotated components by Quartimax method.

	Dimensions		
	Comprehension	Autonomy	Easy of use
Q4 (Realism)	-0.830	-0.280	0.197
Q5 (Self-sufficiency)	0.107	0.748	0.292
Q6 (Time)	0.049	0.848	-0.043
Q7 (Instructions)	0.839	-0.062	0.210
Q8 (Easy interface)	0.316	0.081	0.678
Q9 (Easy Access)	-0.216	0.111	0.845

6. DISCUSSION OF USABILITY AND USEFULNESS

The Technological Acceptation Model (TAM) explains that both usability and usefulness are dimensions which influences over the users' attitude to the technology and, therefore, over its use. Thus, usability must be strengthened to integrate remote labs in the University. I.e., students must consider remote labs as an instrument to be easily used in the practical classes.

Based on the presented reasons, a factorial analysis has been carried out. It has allowed underlying dimensions to be identified. Those are dimensions underlying to those other traditionally used in the analysis of usability of remote labs, (Barrios et al. 2013), (Gampe et al. 2014), (Lowe 2013), (Ormann et al. 2013), (Terkowsky et al. 2012), (Gadzhanov and Nafalski 2010). They have been denominated comprehension, autonomy and ease of use.

On the one hand, the explorative study has made visible possible relations among the attributes of a remote lab class. In this sense, some issues can be balanced each other in a dialectical relationship. For example, a dialectical relationship is identified among the time required to carry out the experiment and the self-sufficiency sense. Therefore, among the experiment instructions and the realism, an inverse

correlation exists. Such correlation must be interpreted as a compensation process between the listed attributes rather than understanding them as conflicting aspects. Regarding the proximity and realism of the remote lab class, according to (Terkowsky et al. 2012), this can be a fundamental line to optimize the remote labs performance within learning framework.

Nevertheless, the contingency analysis has allowed highlighting the positive influence of the three dimensions which constitute usability over usefulness of remote labs. However, any evidence has been found which indicates the strengthening of those dimensions makes that students consider the remote lab as an easier way to learn than the classroom lab. These results use to be the same as those usually found in the study which compares remote and classroom labs. Therefore, it can not be concluded that only the usability management in the design of remote lab guarantee that remote lab is considered as a better technology than the classroom lab.

7. CONSLUSIONS

In this paper, a remote laboratory to carry out lab classes with photovoltaic panels has been presented. Regarding technological issues presented in this paper, open source hardware/software and low cost devices have been used. In

this way, two kinds of Arduino boards have been used to take measurements and to control the different equipment. In addition, a Raspberry Pi has been used to optimize the energy performance of the experimental system and to include a video stream server. Finally, standard Modbus serial communications protocol has been used to unify the communications among the different lab devices. The system access management is carried out by a communications software developed for this purpose (SARLAB). Regarding educational analysis, the first results a high acceptance of remote lab by students. The analysis of educative experience has allowed three dimensions to be identified, which help to understand the usability of the remote lab: comprehensiveness, autonomy and easy of use. They can improve the design of learning experiences. In this sense, this study evidences that the promotion of usability of remote laboratory positively affects the usefulness and acceptance of remote labs. However, we can not conclude that remote laboratories are perceived as a better solution than the classroom.

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