A comparison of remote laboratories for different experimental areas

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Abstract: The objective of this paper is the identification of the variables which affect the acceptation by the students of two kinds of remote laboratories (photovoltaic panels and electric machines) in Higher Education. To achieve it, the Technology Acceptation Model is used and usability and usefulness are the considered factors. Two pilot experiences are carried out over a sample of 86 students which are studying the Energy Engineering Degree. 45 of them (52.3%) carry out the electric machines lab class and 41 (47.7%) the photovoltaic one. After a descriptive analysis, an exploratory and multivariate analysis is carried out. It allows the identification of relations between several variables which affect to the acceptation of both remote labs.

Keywords: Engineering education, Remote lab, Electrical machines, Photovoltaic systems, Pedagogical analysis.

INTRODUCTION

After accumulating some experience in the implementation and use of remote laboratories in higher engineering studies (Mejías, Andújar, & Márquez, 2014; Mejías & Andújar, 2013; Mejías & Andújar, 2012; Andújar & Mateo, 2012; Andújar, Mejias, & Marquez, 2011), we are now conducting pedagogical analysis thereof. With the aim of checking the acceptation by the students of two kinds of developed remote laboratories (photovoltaic panels and electric machines) in Higher Education, a pilot experience is carried out during the second semester of 2013-14 academic period at the University of Huelva, Spain.

The analysis of acceptation gets as reference the Technology Acceptation Model (TAM), (Davis 1986). TAM model is useful to understand the reasons due to any technology can be accepted and adopted by an educative community and by its students. The next statements are proved in TAM framework: a) the students' attitude versus a specific technology depends on their perceptions with respect to its usability and usefulness; b) the perceived usability has a positive effect on the usefulness. The usefulness makes reference to the level in which someone thinks the use of the new technology will improve his/her efficiency. The usability makes reference to the endeavor that someone considers needed to use the technology and make the required work.

Although there are several analysis which have boarded the usability of remote labs in university frameworks, (Tsiatsos et al. 2014), (Gadzhanov and Nafalski 2010), none of them has explored the dimensions underlying to the variable of usability and its relation with the usefulness perceived by the students. The identification and strengthening of those factors in the design of practical classes with remote labs, will allow the improvement of acceptation/adoption of this technology by educative community, (Barrios et al. 2013), (Gampe et al. 2014), (Lowe 2013), (Balamuralithara and Woods 2009), (Ormann et al. 2013).

In this paper, two remote labs are considered. The learning objectives of both laboratories present a lot of similarities. In both cases the aim is the understanding of models of physical/mechanic behavior. In one of them, the behavior of electric machines and, in the other, the photovoltaic panels behavior. However, the kind and function of the augmented reality (AR) techniques used in the laboratories is not the same. In one of them, the AR constitutes virtual complementary information and in the other it is a 3D measurement device. Two lab classes (one for each) are proposed to two groups of students that study the same University Degree.

The remote lab of photovoltaic panels is composed of two photovoltaic panels, a variable light which works as sun irradiance and a variable load. It also has the control device necessary to change the panels connection. Students use the lab to measure and graph different characteristic curves. In addition, they can compare them and understand the effect of sun irradiance in the characteristic curve, as well as the effect of the different connection ways.

The remote lab of electric machines is composed of a synchronous generator driven by a DC machine, (Herrera et al. 2013). The student can vary the field current of the first device, maintaining constant the speed of rotation. The rotation speed is controlled by the current introduced in the rotor of DC machine. The remote lab has got all the devices required to make the vacuum and shortcircuit assays to the alternator. With those assays, the linear model of the machine can be obtained.

After presenting technical and didactic aspects of both laboratories, a comparative analysis is carried out. The objectives are as follows: a) identifying the effects of both laboratories on its perceived usability and usefulness; b) testing, in statistical way, the validity of the variables used as indicators of didactic usability and usefulness; c) exploring the relations between the laboratories usability, their didactic usefulness and the kind of laboratory.

To do the study, a sample is designed with 86 students of Energy Engineering Degree. 45 of them (52.3%) carried out the lab class proposed within the electric machines remote lab. 41 students carried out the lab class proposed within the photovoltaic modules remote lab. The statistical study is based on an anonymous test which is completed by the students after passing the exam corresponding to the subject. It includes issues related to the remote lab usability and its usefulness. Students were required to rate the questions on a 5-point Likert scale (1—strongly disagree and 5—strongly agree).

The paper is organized as follows: section 2 presents the most relevant characteristic of each remote laboratory. Section 3 presents the descriptive analysis of the acceptation of both kinds of laboratories. Section 4 presents the exploratory analysis of usability, usefulness and kind of remote lab. Finally, in section 5 some conclusions are drawn.

2. DESCRIPTION OF THE REMOTE LABORATORIES CONSIDERED

As said above, one of the laboratories is basically composed of an electric machines bench. Specifically, the bench is constituted by a synchronous machine driven by a DC machine. The student must carry out the assay of vacuum as well as that of shortcircuit to the synchronous machine. With this objective, the rotational speed must be fixed along all the assay, while field current is increasing. The student takes note of vacuum voltage or of shortcicuit current, depending on the assay, for each value of field current. Once the corresponding curves have been established, the student can calculate the linear model of the synchronous machine.

The experimental system is designed with the objective of reproducing as well as possible the existent in the classroom lab. Therefore, the voltage and current are measured in visual way by means of a voltmeter and an ammeter. Both measurement devices can be seen in the video image, which is part of the user interface designed to access to the experimental system. The user interface of this first remote lab is presented in figure 1. As can be seen in figure 1, AR techniques have been used to help to the student to identify the different elements which compose the laboratory.

In fact, the user interface includes the next: the live image corresponding to the video signal from the IP camera located in the laboratory; additional elements overlapping to the video image that improve the user interface using AR technics (the labels are interactive, so that the student can access to specific information about each element by clicking on the corresponding label); the control of the input/output elements of the experimental system according to the signals introduced by the student and to the requirements of each experiment; safety extent necessary to ensure the correct use of the bench of electric machines; a table where the student must enter the data directly obtained from the bench of electric machines (these data will be used for the calculations necessary to obtain the linear model of the synchronous generator); a graph that presents the evolution of the controlled signals along the experiment.

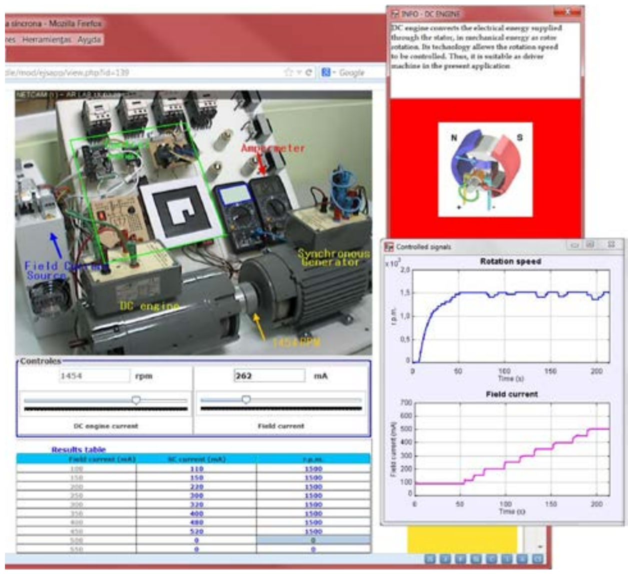

Fig. 1 User interface of the electric machines remote lab

With respect to the photovoltaic panels remote lab, its user interface is presented in figure 2. The most important elements of the video image are the luminary intensity and the panels. The rest of the elements (load, connections and measurement devices) do not show any visual change in the lab class evolution. So, they have been implemented by means of AR techniques.

The students must go increasing the load value and take note of voltage and current corresponding to each load value. In this way, they can graph the characteristic curve corresponding to each irradiance and each connection way. Varying the conditions, different characteristic curves can be graphed and compared. In this way, the students learn the behavior of the photovoltaic panels as previous step to design photovoltaic installations.

Regarding technical issues, to develop the photovoltaic panels remote lab, the next innovative instruments were designed: the use of Arduino board (Arduino 2015) to control a high power luminary; the use of Modbus, (ModBus 2015), to unify the communications among all the components of the experimental system; 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.

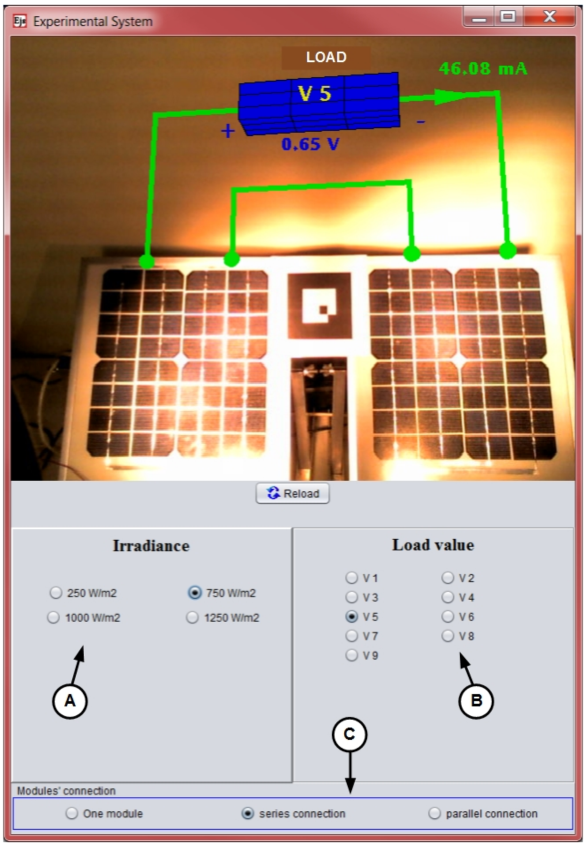

Fig. 2 User interface of the photovoltaic panels remote lab

Finally, a very important characteristic of both developed remote labs is that all hardware and software elements are open-source, so its setting-up and maintenance are low cost. In addition, both user interfaces have been implemented using Easy Java Simulations (EJS) (Esquembre 2015). The user interface corresponding to each laboratory has been integrated in a Learning Management System (LMS), moodle in this case, to which the student can access through a web browser to perform the lab class.

The need for energy has been optimized by means of an I/O board which connect the experimental system when is required by the user and disconnect it when the user stops communications or when there is a network fail.

A communications server is connected to the laboratory intranet as well as to the University corporate network, by means of a communications software designed for the purpose. This server guarantees the necessary links for the students to communicate from their computers to each experimental system in the laboratory. This software provides, automatically, the necessary connections based on the reservations made by the students and on the experiment connection requests. Thus, the access to the laboratory resources and their proper use is ensured.

3. DESCRIPTIVE ANALYSIS OF ACEPTATION OF BOTH KINDS OF REMOTE LABS

Two kinds of variables can be distinguished in the analysis: those relative to the remote labs usefulness perceived by the students and those other relative to the usability. Both sets of variables have been integrated in the study from earlier and similar studies. However, there are not precedent studies which have proven, through statistical keys, the internal consistence of using these sets of variables as indicators of usefulness and usability.

Table 1. Usefulness perceived by the students of remote laboratories

		Total		Overlay information AR		Integration AR		ANOVA	
		Mean	ST	Mean	ST	Mean	ST	F	Sig.
Q 0	Your level on electrical machines/photovoltaic installations is high	3.23	0.890	3.64	0.773	2.78	0.791	26.203	0.000
Q 1	This lab work allows strengthening the theoretical concepts	4.07	0.794	4.00	0.879	4.15	0.691	.727	0.396
Q 2	The remote lab work makes easier the theoretical-practice understanding	3.92	0.690	**4.11**	0.682	3.71	0.642	7.956	0.006
Q 3	The overall assessment of the remote lab is positive	4.10	0.752	3.98	0.753	4.24	0.734	2.742	0.101

Table 2. Perception of usability by students

		Total		Overlay information AR		Integration AR		ANOVA	
		Mean	ST	Mean	ST	Mean	ST	F	Sig.
Q 4	The interface allows carrying out the exercise in the same way as in the lab classroom	4.12	0.818	3.89	0.959	**4.37**	0.536	7.891	0.006
Q 5	The exercise can be carried out without the professor supervision	4.31	0.740	4.11	0.804	**4.54**	0.596	7.651	0.007
Q 6	The time available to complete the tests is enough	4.36	0.796	4.00	0.826	**4.76**	0.538	24.788	0.000
Q 7	The information available in LMS is suitable to perform the lab work	3.97	0.860	4.02	0.892	3.90	0.831	0.413	0.522
Q 8	The use of the interface is easy	4.05	0.810	4.07	0.892	4.02	0.790	0.058	0.811
Q 9	The access to the remote lab through the LMS is easy	4.37	0.704	4.18	0.684	**4.59**	0.670	7.770	0.007

The descriptive analysis, helped by ANOVA (ANalysis Of VAriance), allows next conclusions to be drawn, tables 1 and 2：

1. Regarding the level of competence auto perceived by the students, those who carried out the electric machines laboratory, show levels meaningfully higher than those who carried out the photovoltaic panels.

2. In general, students' perception over the use of remote labs (in both kinds) is positive. Usability and usefulness perceived are high in both remote labs.

3. Regarding the usefulness, there are meaningful differences between both sets of students. In this sense, those who carried out the lab class of electric machines show a higher level of concordance one to each other with the statement of remote labs make easier the theoretical-practical understanding than those who carried out the photovoltaic panels lab class.

4. Regarding the perceived usability, students who carried out the lab class of photovoltaic panels, in general, show a more positive perception of usability than those who carried out the electric machines lab class. The exceptions are the instructions and the interface ease.

4. EXPLORATORY ANALYSIS OF USABILITY, USEFULNESS AND KIND OF REMOTE LAB

In this section, OVERALS (analysis of non-linear canonic correlation) (Van der Burg 1988) is used. It is available in SPSS (Statistical Package for the Social Sciences). There is a double objective: a) highlighting the differences between both kinds of studied remote labs with respect to the usability and usefulness (this variables are related to the acceptation of the remote lab by the students); b) proving that the variables used as indicator of usability and usefulness can actually be.

To do that, firstly, variables are coded again. They had, at the beginning, five categories of answer. Now they have got two categories (positive or negative values).

This is the chosen procedure because it carries out an analysis of non-linear canonic correlation: it consists on finding the common between two or more sets of variables measured in the same sample. In this case, the sets of variables are kind of laboratory, usability and usefulness perceived by the students. It allows the comparison of several sets of variables at the same time and the identification of the internal consistence of each set. Thus, assumptions are not made, since the beginning, about the distributions of variables, neither about their linear relation.

The loss values corresponding to each set of variables in each dimension are used to identify the dimension in which each set is best represented, table 3. Low loss values of each set of variables in each dimension indicate high correlations between the set of variables and the dimension. Thus, it can be observed that the best correlation for set 1 (kind of laboratory) is dimension 1. Therefore, set 2 (usefulness of lab) has got similar loss values in both dimensions, although it correlates lightly better to dimension 2. Finally, set 3 (usability of lab) is which presents the lowest loss values. It correlates better with dimension 2. In conclusion:

- Two different dimensions are identified.
- Dimension 1 explains the highest proportion of variance of kind of lab.
- Dimension 2 explains the highest proportion of variance of the other two sets (usefulness and usability).

Therefore, on the one hand, kind of lab is identified, and on the other hand, a set of variables relative to the acceptation of lab by students is also identified.

The sum of simple setting indicates the capacity of discrimination of each variable in the analysis. I.e., it can be useful to identify the variables which explain the studied fact in the best way. In this sense, the variables which discriminate usefulness in the best way are laboratory (0.787) and theoretical understanding (0.623). Regarding to the set of variables of usability, the variables which discriminate in the best way are time enough (0.275) and instructions (0.405). The consequent conclusion could be that students perceive both kinds of lab in a different way. Making easier the theoretical understanding seems to be a relevant variable (quality) when both laboratories are used. Therefore, the design of instructions and the availability of access time for students are the variables which make the difference. The rest of variables of usability present a low discriminatory capacity.

The analysis of saturations in dimensions (table 3) is equivalent to Pearson correlations between quantified variables and scores of the objects (in this case, students) in each dimension. In this sense, dimension 1 is mainly saturated by the variable laboratory (-0.849). However, there are other three relevant variables of usability: self-sufficiency (-0.505), realism (-0.509) and interface ease (-0.349). On the other way, dimension 2 is saturated by the two variables of usefulness, theoretical understanding (0.637) and easier theoretical-practice (-0.245), and by other three variables of usability: time enough (-0.507), instructions (0.557) and access ease (-0.352).

In conclusion, both variables relative to lab usefulness (theoretical understanding and easier theoretical-practice) correlate to dimension 2. It means that this set has internal consistency. Thus, the used variables are valid to measure the perceived usefulness. On the other way, regarding the set of variables of usability, there are two subsets. The first one is composed of the variables internal to laboratory like realism, self-sufficiency and the interface ease. The second subset is composed of the variables external to the laboratory like time enough, access ease and instructions. Moreover, these external variables are which best correlate to the usefulness to achieve the theoretical understanding. In this sense, it must be said that internal variables present characteristics very similar in both laboratories. As a consequence, they present low explicative capacity. Nevertheless, they must be understood as necessary conditions to benefit these educative resources.

Table 3. Setting, saturations and loss corresponding to the sets

	Set	**Nº category**	**∑ simple setting**	**Saturations**		**Loss**	
				Dimension		Dimension	
				1	2	1	2
1	Laboratory	2	**0.787**	**-0.849**	-0.256	0.279	0.934
2	Theoretical understanding	2	**0.623**	-0.490	**0.637**	0.754	0.553
	Easier theoretical practice	2	0.047	0.111	**-0.245**		
3	Realism	2	0.178	**-0.509**	-0.270	0.334	0.219
	Self-sufficiency	2	0.128	**-0.505**	-0.061		
	Time enough	2	**0.275**	-0.344	**-0.507**		
	Instructions	2	**0.405**	-0.304	**0.557**		
	Interface ease	2	0.140	**-0.349**	0.184		
	Access ease	2	0.154	-0.337	**-0.352**		

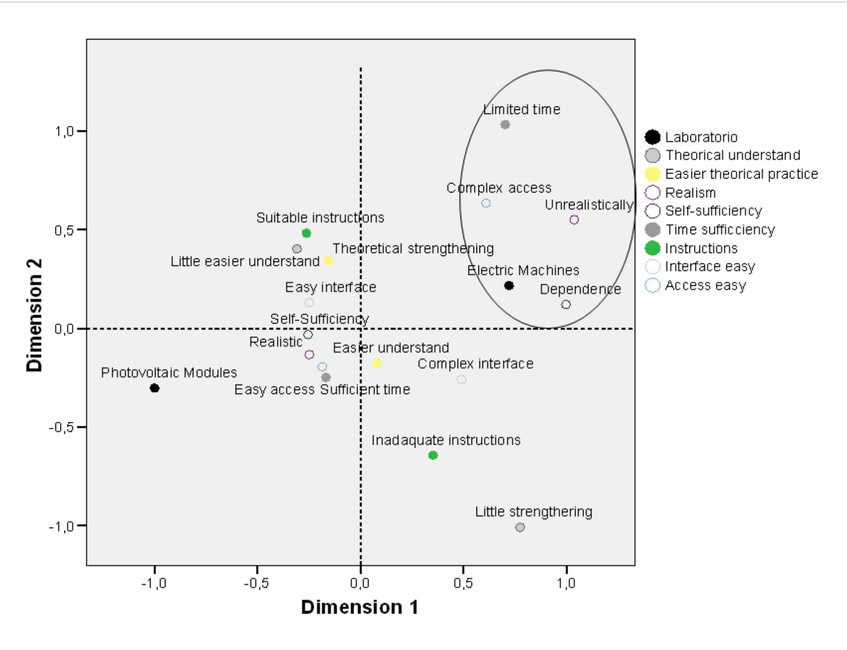

Figure 3. Categories centroids graph

So, only in this study, facing two laboratories very similar, variables external to the laboratory are which make the difference about their acceptation by the students (instructions, time enough, access ease).

The centroids graph (figure 3) allows the visualization of the coordinates of categories in dimensions map. In this way, a global vision of relations/proximities between the categories of the three sets can be observed. The distance between both categories of laboratories attracts attention. In general, a diagonal line composed by the categories centroids can be observed. It is almost equidistant to both laboratories, specially with respect to the perceived usefulness. So, both laboratories are perceived useful in similar way, as a mean which makes easier to carry out the lab classes. And specially useful as a mean to understand the theory.

Finally, in the top right quadrant, where the remote lab of electric machines is located, a zone can be observed which is busy by negative categories relative to the usability. It allows a conclusion to be obtained: students have perceived this lab less useful than the other (photovoltaic). Due to reasons, which should be deeper studied, the remote lab of electric machines is perceived as less realist than the other. Also, it is less autonomous and presents a more complex access.

5. CONSLUSIONS

In this paper, an exploratory analysis has been carried out. It analyses the acceptation (usability and usefulness) of two remote labs by students. The labs have different devices (electric machines and photovoltaic panels). Their learning objectives are very similar. They both are improved with AR techniques, although AR is used with different functions (complementary information versus virtual elements). Therefore, both lab classes have been carried out by sets of students very similar in number, as well as in academic profile.

The descriptive analysis has allowed the identification, in general way, of a better usability of the photovoltaic lab than that of the electric machines. However, the last one has been perceived as a lab which makes easier the theoretical-practice understanding. In this sense, it must be taken into account that students which carried out the electric machines lab show a perceived knowledge of the subject higher than those students who carried out the other lab class.

The OVERALS procedure has allowed the confirmation of the fact that both sets of variables, usability and usefulness, are dimensions very different. So, both sets of variables can be used to measure the acceptation of remote labs by the university students. However, variables used as indicators of usability can be differenced in two sets: the variables internal to the laboratory (self-sufficiency, realism and interface ease) and variables external to the lab (access ease, instructions and time enough). In this study, the variables external to the lab instructions and time enough correlate to perceived usefulness better than the third one.

REFERENCES

Mejías, A.; Andújar, J. M.; Márquez, M. A. (2014). Digital Electronics Augmented Remote Laboratory: DEARLab. International Journal of Engineering Education. 30(4), 950-963.

Mejías, A., Andújar, J. M. (2013). Interaction of Real Robots with Virtual Scenarios through Augmented Reality: Application to Robotics teaching/learning by means of Remote Labs. International Journal of Engineering Education. 29 (3), 788-798.

Mejías, A., Andújar, J. M. (2012). A Pilot Study of the Effectiveness of Augmented Reality to Enhance the Use of Remote Labs in Electrical Engineering Education. Journal of Science Education and Technology. 21(5), 540-557.

Andújar, J.M., Mateo, T.J, (2012). Design of virtual and/or remote laboratories. A practical case. Revista Iberoamericana de Automática e Informática Industrial (RIAI), 7(1), 64-72.

Andújar, J.M., Mejias, A., Marquez, M.A. (2011). Augmented reality for the improvement of remote laboratories: An augmented remote laboratory. IEEE Trans Educ, 54(3), 492-500.

Arduino. (2015, Feb). Open Source Electronics Prototyping Platform [Online]. Available: http://www.arduino.cc

Balamuralithara B, Woods PC. (2009) Virtual Laboratories in Engineering Education: The Simulation Lab and Remote Lab. *Computer Applications in Engineering Education*, 17(1), 108-118.

Barrios, A., Panche, S., Duque, M., Grisales, V. H., Prieto, F., Villa, J. L., . . . Canu, M. (2013). A multi-user remote academic laboratory system. *Computers and Education*, 62, 111-122.

Davis Jr, F. D. (1986). A technology acceptance model for empirically testing new end-user information systems: Theory and results. Doctoral dissertation, Massachusetts Institute of Technology.

Esquembre, F. (2015, Jan). Easy Java Simulations. [Online] Available: http://fem.um.es/Ejs/

Gadzhanov, S., Nafalski, A. (2010). Pedagogical effectiveness of remote laboratories for measurement and control. *World Trans Eng Technol Edu*, 8(2), 162-167.

Gampe, A., Melkonyan, A., Pontual, M., Akopian, D. (2014). An assessment of remote laboratory experiments in radio communication. *IEEE Transaction on Education*, 57(1), 12-19.

Herrera, R.S., Andújar, J.M., Mejías, A. and Márquez, M.A. (2013), Testing Bench for Remote Practical Training in Electric Machines, *IFAC Symp. Advances in Control Education*, 357-362.

Lowe, D. (2013). Integrating reservations and queuing in remote laboratory scheduling. *IEEE Transactions on Learning Technologies*, 6(1), 73-84.

Modbus (2015, Mar). [Online]. Avaible: http://modbus.org/

Ormann LBH, Steinberger M, Kalcher M, Kreiner C. (2013) Using a Remote Lab for Teaching Energy Harvesting Enhanced Wireless Sensor Networks. *IEEE Global Engineering Education Conference*, 1109-1117.

Raspberry Pi (2015, Apr). [Online]. Available: http://www.raspberrypi.org.

Tsiatsos T, Douka S, Zimmer T, Geoffroy D. (2014) Evaluation Plan of a network of remote labs in the Maghrebian countries. *International Conference on Remote Engineering and Virtual Instrumentation*, 200-203.

Van der Burg, E. (1988). Nonlinear canonical correlation and some related techniques (Vol. 11). DSWO press.