Different Uses for Remote Labs in Electrical Engineering Education: Some Considerations on the Preliminary Results of an Ongoing Experience

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Abstract. Laboratories are a fundamental part of engineering education due to the very nature of the engineering profession. This is a characteristic of all engineering courses, though it may vary from one curriculum to the other and even in the same curriculum. This paper is dedicated to the analysis of different applications of a remote lab in an Electrical Engineering curriculum. If the types of experiments it offers are concerned, it is classified as an Electric and Eletronic Circuits lab; one in a set that also has Digital Electronics, Analog Electronics, Electrical Machines, Control Systems, etc. But it is not a traditional lab – it is a remote lab, with traditional components remotely accessed over the Internet. This work presents the preliminary results of the deployment of VISIR – a remote lab for Electric and Electronic Circuits in some courses. It discusses the different course contexts and how the use of VISIR was adapted to each one. Results of students' opinions are presented and discussed.

Keywords: Remote Labs; Electric Circuits; General Electricity.

1 Introduction

Laboratories are a fundamental part of engineering education due to the very nature of the engineering profession. Feisel and Rosa [1] classified engineering laboratories in three groups: development, research and educational (instructional). The last group is used by students during their engineering courses and this work is focused on them. Electrical Engineering courses rely on different types of labs – Analog and Digital Electronics, Control Systems, Microwave Circuits, Electrical Machines, etc. In many research institutions, students can also have access to research labs, but this fact does not mean that the institution can exclusively rely on them; educational labs are a need and are used by institutions worldwide.

adfa, p. 1, 2011.

Current ICT – Information and Communication Technology provides many options for engineering education. Some are solely software, like general-purpose products for numerical computation such as MATLAB® and Maple®, both commercial, and SciLab®, which is a free and open software. Other products are specific; CircuitLab®, Cadence®, LTSpice and Fritzing are based on numerical computation but they solve electric circuits problems. The first two are commercial; the others are free.

The use of ICT is so important that Froyd et al. [2] consider it the fifth major shift in Engineering Education in the last 100 years. The authors even extend the acronym to ICCT - Information, Communication and Computational Technologies.

ICT has also brought a new world of possibilities through the deployment of Remote Labs. The expression Remote Lab in the context of this work is "Remote Access - Real Resource" in the classification presented by Heradio et al [3].

This paper presents the preliminary results on the use of VISIR – Virtual Instrument Systems in Reality, a remote lab for Electric and Electronic Circuits (EEC), that was deployed and started being used at Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio) in the second semester of 2016. It has been used for two semesters in different courses. This short experience with VISIR has indicated that its use must carefully be planned to suit the needs and the context of the institution and its courses. This paper is divided in 5 sections and describes the main actions and results. Section 2 addresses the context at PUC-Rio and presents VISIR. Its introduction and use as a learning supporting tool are discussed in section 3 while section 4 shows the main results of the experiences in different courses. Conclusions and comments are in section 5.

2 The Context at PUC-Rio and VISIR

PUC-Rio is a private and non-profit university in Rio de Janeiro, Brazil. The courses related to Electrical Engineering and Electricity Fundamentals in other engineering curricula have been using different types of ICT tools for about two decades. Blended learning (b-learning) was introduced in the first term of 2014 and since then some courses started being offered in this mode.

VISIR is a remote lab for doing real, physical experiments with EEC. The acronym VISIR stands for Virtual Instrument Systems in Reality.

This section is divided in two subsections: the first describes the context at PUC-Rio and the other focuses on VISIR.

2.1 The Use of ICT Supported Learning at PUC-Rio

The context of ICT supported learning is presented in three steps as follows:

- The Maxwell System (http://www.maxwell.vrac.puc-rio.br/) is a platform that integrates an IR - Institutional Repository as defined by Lynch [4] and an LMS – Learning Management System as defined by Wright et al. [5]. The IR features of the system manage all types of digital contents from ETD – Electronic Theses and Dissertations to interactive courseware of many different types. It hosts both inputs to the learning process as well as its outputs. Since it is an integrated system, students and faculty using the LMS features have seamless access to all types of digital contents. Over and above, contents are items of the collection and not deposited on course folders; courses point to contents that are not replicated, each one has a unique existence on the platform.

- The first integration of the Maxwell System with an external system – simulation is an important tool in Engineering Education. In order to offer students learning objects that include simulation, the system was integrated with SciLab®. Students, both graduate and undergraduate, and faculty are developing objects that address important topics. When the implementation of VISIR in undergraduate courses began, a set of objects to support EEC was developed. Currently, there are 19 such objects in Portuguese and 10 translations into English; three additional objects are under development. Since SciLab® is a software product, it was installed on a server that is connected to the Maxwell servers.
- The second integration – this was quite different, since the other system was a Remote Lab; it had hardware and software to be integrated. It had the same objective as the first – VISIR was considered one additional learning resource to be offered students and faculty, and it had to seamlessly be accessed. In order to achieve it, both the IR and the LMS features of the Maxwell System were used. The integration is presented in [6].

The main idea behind the use of ICT tools to support students and faculty is to integrate solutions that are flexible enough to be expanded so that new ones can be added when necessary.

PUC-Rio also offers students and faculty other IT solutions; the ones mentioned in this subsection are related to Electrical Engineering only (we are considering Computer Engineering and Control and Automation Engineering as Electrical Engineering subtypes). There is a campus agreement for MATLAB® - students can use it on the computers of the university labs, on-line from the company servers or download it to their own devices. The university also provides LabView® on computers in labs of the Electrical Engineering Department and CircuitLab® in the labs and through the Internet.

2.2 VISIR

VISIR is comprised of two parts – software and hardware. The VISIR software is an open-source released under a GNU General Public License (GPL) [8]. It includes (1) an user interface that handles all the administration, access, and authentication process. This interface may sometimes be invisible to the client depending on how VISIR is integrated into a given Learning Management System (LMS). In the case of PUC-Rio, where VISIR has been integrated into the Maxwell System, only the (2) experiment client interface is visible to the students. The experiment client is a simulated electronics workbench embedded in the HTML code of the user interface. It provides access to a triple-output DC power supply, a digital multimeter (DMM), a two-channel oscilloscope, a function generator and a solderless mounting board (breadbord), as depicted in figure 1. The top row of the interface shows the electric and electronic components that are available for a given experiment, where these components are physically located in a relay-based matrix that is connected to a PXI system; it contains the 4 instruments referred in the previous sentence. The matrix and the PXI system form the hardware part of VISIR. The (3) measurement server is responsible for handling all the remote experiment requests. Every time a client clicks on the "Perform Experiment" button, it reads the circuit description, as built by the client in the experiment client interface, checks if the circuit is valid and then queues the requests to (4) the equipment server, which physically interconnects the components and the instruments in the matrix, applies the stimulus, reads the responses, and then passes this information back to the experiment server that transmits it to the active remote instrument panel. All these operations are done in a fraction of a second, so VISIR can be described as a batch-mode remote lab, capable of simultaneously serving several clients. In short: the user and experiment interfaces plus the experiment and instrument servers are the software, while the hardware part contains a relay-based matrix and a PXI-system with a DC power supply, a DMM, an oscilloscope, and a function generator.

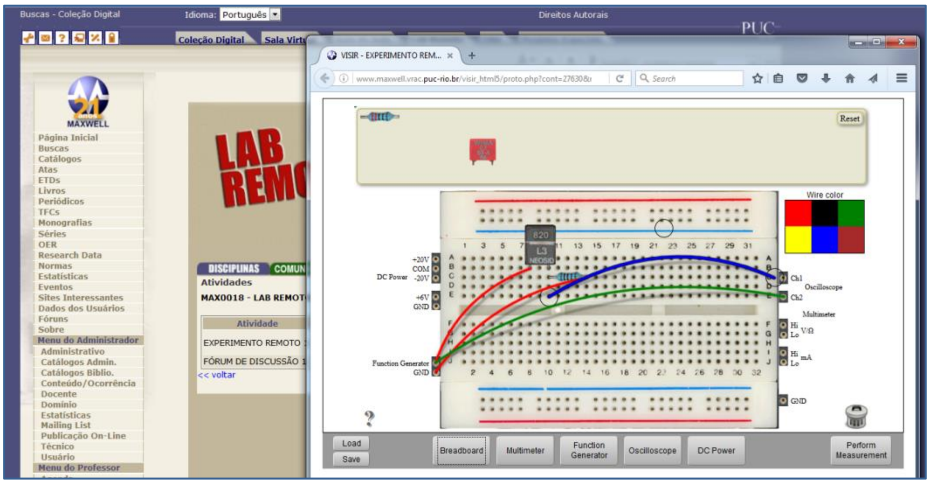

Fig. 1: Experiment client interface (in HTML5) integrated into PUC-Rio Maxwell system.

2.3 Final Remark

The use of VISIR in different courses, except for the trials that were performed in the first semester of 2016 using the installation at CUAS – Carinthia University of Applied Sciences, ran from the integrated platform at PUC-Rio.

3 The Use of VISIR

Different courses in one curriculum and courses in different curricula have distinct characteristics. The distinctions are even bigger when courses of different institutions are considered.

This yields an interesting situation – examining course characteristics to find better uses of the Remote Lab. The use must be adapted to objectives of the course and the context of the institution. This is something that was learned in the second semester of 2016 when VISIR was used for part of the lab activities of the Electric and Electronic Circuits (EEC) course. From the results of this experiment, it was decided to be used in other courses with different objectives and profiles of students. Two other courses at PUC-Rio were chosen – General Electricity (GE) and Introduction to Engineering/Electrical Engineering (ItE). At the same time, the VISIR$^+$ Project requires that local partner institutions use the equipment. One of the partners decided to start using; it was Universidade do Estado do Rio de Janeiro (UERJ) and the course was Electric and Magnetic Measurements (EMM). The subsections that follow address different uses of VISIR and how results of this experience are being used to find the way that will most benefit the learning process.

3.1 Learning to Use VISIR

VISIR was the first remote lab to be used at PUC-Rio, so faculty involved on the VISIR$^+$ Project decided to get acquainted with the equipment and its use before the actual installation at the university. CUAS is PUC-Rio's corresponding partner in the project, so its equipment was offered for this first use.

In the first semester of 2016, two experiments were held using the VISIR installation in Austria. The first was for one experiment in the EEC course and the second in an extracurricular activity (ECA) aiming at students that had not taken the Circuits course; ECAs are mandatory in the Engineering curricula in Brazil.

First Experiment in EEC. We have selected a single experiment of EEC for adding an extra step, using VISIR, between simulation and real-lab practice. We had 12 valid responses from the 18 students that were enrolled in the lab class in three different questions: (1) I found VISIR easy to use; (2) VISIR helped reducing experimental setup errors / setup time; (3) Overall, VISIR had a positive impact in my learning experience. Assigning grades from 1 ("I completely disagree") to 5 ("I completely agree", the questions had average answers of 4.8, 3.5 and 4.6, respectively. Further research showed that question 2 had not a high score due to lack of circuit components for that especific lab class.

First Experiment in an ECA. The ECA using Laboratories of Electrical Engineering took place with 11 students from electrical engineering (6 students), mechanical engineering (3 students) and computation (2 students). Based on the evaluation from the students' viewpoints, the activity was successful. Most of them (6 students) assessed the activity with the grade 5 (on a scale from 1 to 5), 4 graded 4 and one graded 3. Most of them would recommend (3 students) or strongly recommend (8 students) the activity for their colleagues. In addition to that, the activity allowed presenting the VISIR to students and defining the best strategy to allocate the new technology into the regular courses.

Comment. These two uses of VISIR were of paramount importance in learning how to prepare and run experiments in the following school terms. The insights from these experiences led to the view of the implementation process as presented in [7].

3.2 VISIR and the EEC Course in the Second Semester of 2016

EEC is a mandatory course in three curricula at PUC-Rio – Computer Engineering, Controls and Automation Engineering, and Electrical Engineering. It has been taught in the blended learning mode (b-learning) since the first semester of 2014.

This course has had high rates of students who do not pass it, either they dropout or fail the exams. This is a serious problem since EEC is a prerequisite of many other mandatory courses. Two members of the VISIR team have taught this course and started collecting data about the students' performances in 2011. Since then, many actions have been taken to enhance the performances. Many actions are based on the use of ICT tools – development of learning objects of different natures (animations, videos, simulators, etc). The switching to b-learning is one of them.

There are two lab hours per week taught in a traditional way. VISIR was added as an additional activity to offer one more way of experimenting with circuits.

The Experiments Students Must Perform. In the last terms, students have performed 10 experiments: (1) Resistor ladder circuit; (2) Operational amplifier (inverter and non inverter); (3) Amplifier and adder; (4) Sensor with graphic bar; (5) Super diode; (6) First order circuits (RL and RC); (7) Timer (RC); (8) Second order circuits (RLC; (9) Sinusoidal steady-state; and (10) Frequency response (RL, RC and RLC).

How Students Work at the Lab. Students are required to study before going to the lab. They are assigned a study guide and they have to write an outline of the way the experiments will be performed and the expected results; they are graded for this activity. They also have to simulate experiments (using CircuitLab®) before going to the lab and the results are part of the outline. As mentioned before, they have two hours of lab classes each week but the labs are open from 7 AM to 7 PM every weekday and there are technical staff to support students all the time.

Experiments Using VISIR. The use of VISIR was limited to three experiments: (1) Second order circuits (RLC); (2) Sinusoidal steady-state; and (3) Frequency response (RL, RC and RLC). Students were required to perform one additional task before going to the lab – use VISIR to remotely perform the experiments.

Preparation of the Course for the Use of VISIR. In accordance with the view of the implementation process presented in [7], many items of courseware were developed; they can be found in the series Projeto VISIR^{+} (https://www.maxwell.vrac.puc-rio.br/series.php?tipBusca=dados&nrseqser=14). Many other supporting learning contents were developed and can be found in two other series: Objetos Educacionais em Engenharia Elétrica (https://www.maxwell.vrac.puc-rio.br/series.php?tipBusca=dados&nrseqser=5) and Simulações em Engenharia Elétrica (https://www.maxwell.vrac.puc-rio.br/series.php?tipBusca=dados&nrseqser=12). All other courseware developed for the b-learning mode were available as well.

Grades and Results. A lot of data were collected: the students' GPAs, the numbers of times they had already attended the course, their curricula, etc. The class had 36 students and and 3 dropped out; 33 was the final number. The students were handed a questionnaire at the end of the term – 17 (51.51%) filled it but 3 were not identified. This remark is important because it was only possible to match grades with VISIR activities for 14 students. The students were graded by the outlines they presented; 3 had 3 parts because they included VISIR and the remaining 7 had only 2. This is something that is commented later. They were also graded by their performances and reports on the experiments. Finally, a test was applied and graded. The final grade of each student was 30% from the average of outlines (1), 30% from the average of experiments and reports (2) and 40% from the test. Table 1 shows the average grades for all 33 students. Grades are computed over 10.

Table 1. Average grades for the EEC lab in the second semester of 2016.

Types of Grade	Values
Average of all outlines (1)	6.91
Average of all experiments and reports (2)	7.93
Avarage of all tests	4.55
Average of final grades	6.27

When the results of the whole EEC course are considered (lab and theory), the results in terms of grades are shown in figures 2 and 3.

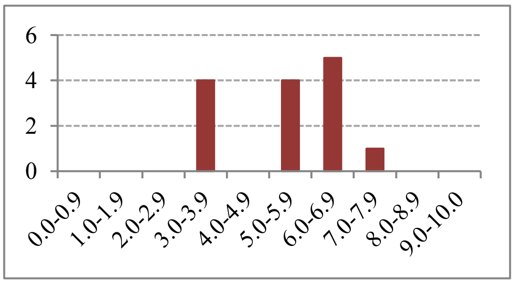

Fig. 2. Numbers of students by final grade – set that were identified in the questionnaire.

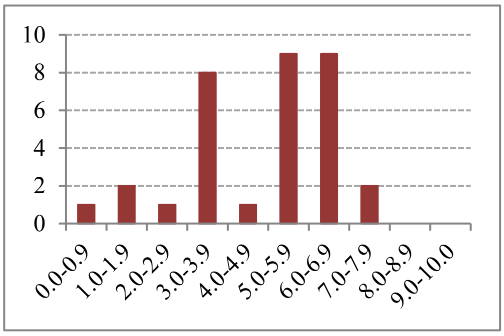

Fig. 3. Numbers of students by final grade – all students in the class.

Gathered data show that students who were identified when replying the questionnaire: (1) represented 42.42% of the class and 50.00% of those who passed; and (2) 28.57% were taking the course for second time as compared to 30.30% of the class. The histograms show that the identified students had less unsuccesses. It yields the impression that more dedicated students were concerned in expressing their opinions on the use of VISIR.

The overall average of points in the evaluation of VISIR was 1.99 over a maximum of 5.00. The average number of accesses was 3.96. Some comments were interesting: (1) the weight of experiments outlines requiring different numbers of tasks was the same – a bigger workload was not recognized; (2) the labs are open many hours a day, so the use of a remote equipment does not add that much value; (3) it was difficult to tell the difference between VISIR and a software product; and (4) the student can not perform experiments that are not assembled on the equipment and this can be done in the traditional lab. It is important to remark that experiments used in the course did not explore the potential of the equipment to perform tasks that would not be possible in the traditional lab, as for example, the determination of a Thévènin Equivalent Circuit or the identification of a transfer function of a 1st or a 2nd order circuit; the use of VISIR would allow components to be "hidden" from students.

3.3 Open House to High School Students in the First Semester of 2017

PUC-Rio regularly invites students from public and private schools to visit the University and attend lectures and technical activities. In the first semester of 2017, 60 high school students had the opportunity to use an Electrical Engineering lab. It was possible because they used a remote lab. During 1 hour the students performed basic experiments. The objective was to present results of a real laboratory in a safe way. Overall, the activity was successful since the computers, internet and the VISIR equipment worked as expected.

3.4 VISIR and the GE Course in the First Semester of 2017

This course is mandatory to all engineering students who are not required to take EEC. It has a very large number of students and the number of lab classes in the first semester of 2017 was 14 – the toal number of students was 273. The number of students who filled the questionnaire was 235 (80.08% - much higher than that of EEC).

This course offers only one hour of lab classes per week and they are on different days and times. This poses a problem – to keep the experiments in sync, the number of experiments to be performed each term used to be 8. Faculty became very enthusiastic with the use of VISIR in order to: (1) increase the number of experiments each term; (2) offer more lab time to the students; and (3) motivate students who are not involved with electricity related curricula by the use of a new tool. Concerning the number of experiments, it is important to remark that holidays do not impact a remote equipment and, also, experiments can be available for many days since no technical supervision is required; students can not work in the traditional lab if a technical staff is not present. Three new experiments were added – one divided in 3 steps. This meant a significant enhancement in the number of practical activities.

It is important to remark that GE deals with voltages and currents much higher than VISIR supports. At the same time, basic concepts like Ohm's Law, voltage divider, current divider, linear and nonlinear circuits can be addressed with VISIR with no loss of generality.

The computation of the results of the questionnaires yielded an average grade of 2.48 out of 5.0; better result than that of EEC. The average number of accesses was 7.63; almost twice as much as that in EEC. An inspection of the logs of accesses on the Maxwell System showed significant numbers late at night and during weekends. Thus a "mission" of a remote solution seems to be fulfilled – offer students access to resources when the university is closed.

To illustrate the impact of the VISIR, figure 4 presents the grades as functions of numbers of access. In addition to that, a trend line was draw to show that, in the average, the more the students has accessed the VISIR the higher their grades were.

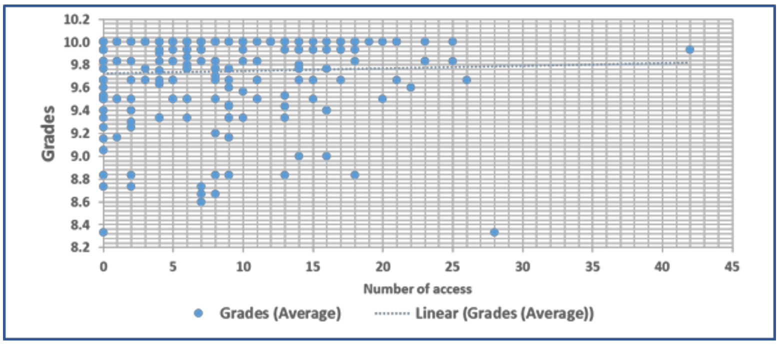

Fig. 4. Grades as functions of accesses.

This course is using VISIR in the second semester of 2017.

3.5 VISIR and the ItE Course in the First Semester of 2017

Introduction to Engineering is a Problem Based Learning (PBL) course that is mandatory to all students admitted to one of the engineering curricula. It is taken in the first semester and students are generally grouped in classes the same area of interest. VISIR was used in a class with 17 students distributed in the curricula:(1) Computer Engineering – 1 ; (2) Control and Automation Engineering – 4; (3) Electrical Engineering – 4; and (4) Mechanical Engineering – 9. The focus of their PBL projects was electromechanical systems controlled by microcontrollers. The faculty responsible for the class is in the area of Electrical Engineering.

The computation of the results of the questionnaires yielded an average grade of 2.50 out of 5.0; also a better result than that of EEC. The number of students who finished the course was 17, the same number of students who filled the questionnaire. Among the 17, 13 wrote comments and 9 said that they liked because they could use it any time and any place. One interesting comment was that the student felt comfortable by not risking damaging the equipment. The average number of accesses was 19.35.

3.6 VISIR and the EMM Course in the First Semester of 2017

As mentioned before, the VISIR$^+$ Project requires that participating institutions have local partners. UERJ is one of the partners and was the first to use VISIR. It is a public institution that belongs to the State of Rio de Janeiro. The course that was chosen by UERJ was Electric and Magnetic Measurements which is mandatory for the curriculum of Electrical Engineering. The number of students was 15 and 7 replied the questionnaire. The average number of accesses was 10.93 and the average grade was 3.0. All questionnaires had comments – 2 students liked the anyplace anytime possibility of use and three had problems with the instruments. One interesting comment was that the student felt comfortable by not risking damaging the equipment, the same as in ItE. This course is using VISIR in the second semester of 2017.

4 Main Outcomes

The first outcome of the VISR$^+$ Project at PUC-Rio was the introduction of a remote lab in Engineering Education which has been benefitting from other ICT tools.

The second is that the original idea presented in [7] seemed to be right – deploying a remote lab is a project that has many different aspects. It is an educational project that must be integrated with the ongoing learning activities. Students and faculty must feel that a new tool is available to be added to others. Faculty must make sure that course activities using the remote labs must carefully be planned.

The third is that VISIR is very well suited to some courses but not to others. In the EEC course, results were not good when VISIR was employed in many different lab experiments. There was not a real need of a remote lab to provide support to experiments that can be performed in the many hours that the traditional lab is available. At the same time, faculty did not implement the experiments that would only be possible using VISIR.

Nevertheless, we see a huge opportunity for VISIR in EEC in the near future. Students of Electrical, Control and Automation and Computer Engineering enrolled in the university since the first semester of 2017 are now required to attend two EEC courses – EEC I and EEC II – where the traditional lab is not used until the second course. This means that students of EEC I will not have hands-on lab experiments, and VISIR will be used independently.

On the other hand, the use in GE, ItE and EMM were quite satisfactory. Faculty of GE are enhancing the use of VISIR from the experience they got the first time they used it. GE has many students, so this yields a big impact, specially because students in this course are not really motivated to courses related to electricity.

5 Conclusions and Comments

The use of VISIR as one of the steps before traditional laboratory classes of the same experiment did not yield good perceptions among students, since they could compare with the traditional lab where there was a lot more flexibility. At the same time, using VISIR to introduce experiments that are not performed in the traditional way seemed to please students. Faculty were specially satisfied that they could add more experiments to the courses and/or better motivate their students. The use of VISIR in courses other than EEC yielded better results. The grading process was also a problem in EEC.

With the introduction of a new curriculum where EEC will be divided in two courses, we see an opportunity for VISIR in the first course (EEC I), as all traditional lab experiments were left to EEC II. This is expected to add real value to EECI since students will be able to experiment using concepts that are theoretically taught.

The results discussed in this paper are limited by a very short time frame – one semester in each course. For this reason, it is not possible to state that VISIR helps students achieve better results. Maybe students who access the remote lab more times than the others are more committed to learning regardless of the tools used. Two courses (GE and EMM) are currently using VISIR for the second time, so there will be more data to analyze. The VISIR team has no doubt that this study will have to be performed once the equipment has been used for more semesters.

A more extensive and intensive study was performed by Marques et al. [9]. Many of results of this first use at PUC-Rio are in agreement to the results presented in this work

A comment is necessary to wrap up: there is a large amount of data already available on the Maxwell System that will be analyzed and presented in a next publication.

6 Aknowledgements

The VISIR team at PUC-Rio is very grateful to the VISIR team at CUAS for its goodwilled lending of the equipment and competent support in the process of installation.

The VISIR+ Project is funded by the European Commission through grant 561735-EPP-1-2015-1-PT-EPPKA2-CBHE-JP. The PUC-Rio team is grateful for this opportunity of having VISIR and being part of such important project.

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