# Design and Development of Physics Remotely Controlled Teaching Laboratory (RCL): The Case of Light Attenuation Passing through Transparent Materials Experiment

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**ABSTRACT**— *Understanding the basic concepts of physics and the development of skills that will enable students to realize the natural processes, as well as becoming familiar with the measuring devices, requires experimental laboratories as a real learning environment. Over time, two main types of experimental laboratories have been incorporated into the strategy of teaching Physics: the hands-on and the simulation laboratory. In recent years, especially with the proliferation and development of web-based technologies, the remote-access laboratory has appeared as option, which requires less space, less time, and less financial resources, as experimental setups are automated and experiments are performed online. In this study, a method is presented, for operating a remote, first year undergraduate Physics teaching Laboratory, using web-interface techniques that enable students to fully control the whole experimentation process. This technology, which is based on a server–client approach, allows the implementation of physics experiments via Internet without requiring expensive equipment or software. In addition, a physics experiment in Optics is also described, already available as a sample application, according to which the optical attenuation of light is studied as it goes through optically transparent materials; it can also be carried out by the students via Internet in real time. Students, by the use of an interface, which is a dynamic webpage, can alter parameters and make quantitative measurements, which can then be analyzed. In conclusion, the qualitative characteristics of the educational results achieved and the experience of the operation of a remote experiment are given.*

**Keywords —** Remotely Controlled Laboratories, RCL, Physics teaching Labs, Online Education, ICT

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## 1. INTRODUCTION

In the educational strategy of teaching Natural Sciences, the focus up to recently was on the activities based on the experience acquired by hands - on lab experiments [1]. Nevertheless, access to real laboratory environments may be limited due to high costs, risk or inability to get access to (people with disabilities). However, today's technological evolution has led to the creation and use of tools that enhance and sometimes replace traditional labs with the use of computers [2].

The improvement of laboratory experience through the use of simulations has, for a long time, kept researchers involved in the development of information technologies busy [3]. While simulations have been widely adopted in education, many if not most instructors feel that an important pedagogic feature is missing: the immediacy of the actual laboratory environment in contrast to simulation laboratories that form a virtual environment. Despite their advantages, they are considered to be a "poor" alternative to the experience that real labs offer, mainly because the holding environment is idealized and, therefore, the results which are produced, while the factor of interaction with real

equipment is absent [4],[5].

During the last twenty years, the rapid exponential growth of Internet has had a huge impact on education generally and particularly on higher education. New technology has brought significant improvements to student learning experiences and, at the same time, to communication and immediate diffusion of knowledge among members of the academic community. The development of a standard web interface and a common software platform, like the MIT[1] iLabs, that can be used by other higher education institutions, has created the Online or remote laboratories [6] as an alternative to conventional laboratories.

These labs use computers for collecting, processing and evaluating data from actual experiments, without requiring the physical presence of students in the same room with the experimental setup [7]. Remote control labs provide access to laboratory environments that would otherwise be inaccessible to students due to high costs or risk, such as nuclear physics laboratories [8]. These technologies have given new life to experimenting from a distance, making it possible to conduct real experiments via a simple web page. A multitude of remotely controlled (and accessed) laboratories (RCL) has been set up by combining the capabilities of microcontrollers with those of web technologies and programming languages. Students can, via Internet, perform experiments in real time, since they watch live streaming from the experiment taking place, an interactive interface to control the experimental procedure and the resulting data required for the relevant analysis and evaluation [9].

According to M. Sauter et al. [7], a crucial question with regard to the learning experience of students performing an Online experiment is whether they feel that they are in an environment in which real scientific work is running, since the controlling of the experimental setup and the handling of equipment is done from a distance. This question has been answered in a number of related research [3], [10], [11], [12], [13], [14], in which substantial differences in learning outcomes between the traditional and remote access laboratories have not been recorded. More than 90% of the surveyed students considered the effectiveness of the Online lab as an equivalent (or better) to that of the real laboratory [11]. In the field of Physics, until recently, the remote control and measurement techniques were applied to experiments where the presence of students was not easy, e.g. nuclear physics or high-energy physics experiments. Nowadays, these techniques are increasingly integrated into distance education [15], [16], [17].

In this work, an attempt has been made as a first approach to the creation of remotely controlled via Internet undergraduate Physics teaching laboratories. For this purpose, we redesigned an optics experiment which is included in the curriculum of Physics in several Departments of the Institution in such a way that it may be integrated into an automated laboratory environment. Students, through a HyperText Markup Language (HTML) page, can carry out the experimental process in real time. The application, via the interface, accepts parameters, performs the experiment and presents the results in a table by creating, at the same time, the corresponding diagram. On completion of the experimental procedure, a file of the measured values is made available to download. The use of Open Source software, combined with low equipment cost such as using Raspberry Pi instead of a desktop computer, enable the development of a flexible (in terms of space allocation), affordable and innovative Physics laboratory that is remotely controlled, thus maximizing the ease of access for undergraduate students.

In the remaining part of this paper a brief reference is made to international practice by presenting relevant work on the subject done by university research groups (2nd section). Then the experimental setup is presented and the relevant physical concepts are analyzed (third section). Furthermore, a description of the technology that allows the Online student connection with the lab is provided (4th section) and, finally, the conclusions and perspectives for future work are presented (5th section).

## 2. RELATED WORK

The first efforts in developing remote educational undergraduate labs began in the mid-90s. In relation to Physics teaching, the first such experiment was to measure the speed of light [18].

With the development of new web technologies and advanced, easy to use, instrument controlling software as well as a series of other elements incorporated in an experimental apparatus, in recent years, there has been an increase in the development and use of remote laboratories accessible from the Internet. In the last two decades, two European projects in educational technology dealt with the Physics remote labs. The first one was the Pearl project which completed its work in 2003. In this project, the following institutions participated: Open University (UK), University of Dundee (Scotland), Trinity College (Ireland), Universade de Porto (Portugal) and the Greek company Zenon, SA [19]. The aims of PEARL were the development of a system that would enable students to perform, from a distance, experiments in real time and the assessment of its educational potential [20]. The design was based on Internet and multimedia technologies.

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[1] The iLabs Project at Massachusetts Institute of Technology with url address:
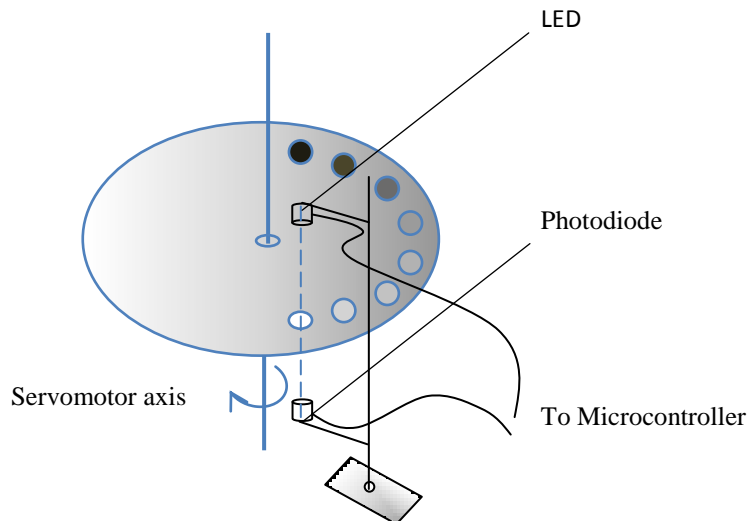http://ilab.mit.edu/iLabServiceBroker/default.aspx

A key parameter of its function is that it allows the cooperation among the students during the conduct of the experiments [21]. The second is the RCL project[2], in which Online classical Physics experiments, both at a high school and university level are conducted. These experiments are accessible to anyone with a simple Internet connection. The interface between the user and the experiment is done via a web page, on which the experimental setup from the laboratory is displayed live by the use of a video camera.

Furthermore, the experiment controls together with the data tables are shown on the page with values collected for analysis in real time [22]. In addition, by initiative of eight European universities and three companies, the LiLa (Library of Labs)[3] Program has been established in which Virtual and Online experiments are shared among the universities by means of a web portal. In Europe, there are other research groups, mainly of higher Institutions, involved in smaller projects such as the WebLab-Deusto project created by a team of the Spanish university Deusto. Within the framework of this project, remote labs for its students have been built, mainly in the Engineering field, through an open source software platform that is distributed for free on their website[4]. At this point, it is worth mentioning the Go-Lab Project[5], which is aimed at secondary school students, providing remote and virtual laboratories in the field of science.

It is true that the growing interest in creating remote access laboratories and the need for universities to cope with the decrease in their funding, has led the efforts of researchers to developing systems that enable many educational institutions, by means of cooperation, to share their resources and, at the same time, achieve economy of scale. The basic idea is that each Institution develops a series of experiments used by students of all the other Institutions, through a common software platform. There are several attempts recorded in this category, the most important being the creation of the iLabs MIT platform, which has been used by many universities around the world since 2008. In the same category falls the public funded Australian project LabShare[6], which focuses on developing a network of remote access laboratories. It is also significant to note that in the recent years a much more flexible system has been developed, allowing remote access via Internet, suitable to all fields of science. This is a project called RWSL (Remote Web-Based Science Laboratory) , the main aim of which is to develop a general use software and robotic hardware platform that will make possible the development of remote access laboratories in fields besides Engineering[7].

## 3.  THE EXPERIMENTAL SET-UP

This experiment is designed to teach first year undergraduate students light attenuation as it passes through materials of varied thicknesses. The absorption coefficient of pigments that covers the surface of the materials or alternatively



**Figure 1:** Experimental Apparatus Diagram

contained in them is thus determined.

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[2] http://rcl-munich.informatik.unibw-muenchen.de/
[3] http://www.lila-project.org/
[4] http://weblab.deusto.es/website/
[5] http://www.go-lab-project.eu
[6] http://www.labshare.edu.au/
[7] Details about the project can be found on the platform: http://www.nic.bc.ca/rwsl

The apparatus employed in the experimental procedure is presented in Figure 1[8]. On the rotation axis of a DC electric servomotor, a disc of an opaque plastic material with circular openings distributed over an arc of $0 – 180^o$ degrees was placed. All the openings, except for the first one, were covered with coloured celluloid sheets of gradually increasing thickness acting as increasingly opaque filters. The first opening was left intentionally uncovered so as to measure the initial amount of light from the source, for reference purposes. Moreover, the LED used as source was fed by a constant 3V voltage and a common photodiode sensitive to the visible electromagnetic spectrum placed perpendicularly to the disc. The photodiode instantly detects the amount of radiation, passing through a specific opening each time, and converts it to an electrical signal that is sent to a microcontroller for recording purposes.

By setting values in the corresponding field of the HTML page, where the interface between the user and the experiment is hosted, we can control the rotation angle of the servomotor axis via the microcontroller and, therefore, the rotation of the disc in a 0 - 180 degrees fashion. In this sense, one can select the thickness of the material the opacity of which is to be measured. The electrical signal produced by the photodiode is proportional to the intensity of the incident radiation. For each set value, the microcontroller reads its analogue input which is connected to the photodiode, converts the values to intensity units I and produces the Intensity vs. thickness diagram which is displayed on the interfacing web page. At the same time, a data file is created, which can be downloaded at the end of the experiment and stored in a computer for further processing and analysis.
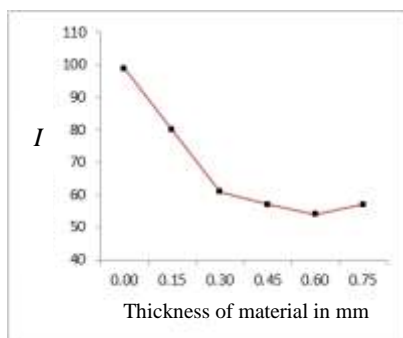
The Beer-Lambert law relates the attenuation of light to the thickness and the specific properties of the material through which the light is passing. The mathematical expression is given by:

$$I = I_0 e^{-\mu x} \qquad (1)$$

where *I* is the light intensity after it passes through the material and $I_o$ is the initial light intensity (Figure 2). From the above relation we get:

$$I = I_0 e^{-\mu x} \rightarrow \frac{I}{I_0} = e^{-\mu x} \rightarrow \ln\left(\frac{I}{I_0}\right) = -\mu x \qquad (2)$$

which is of the type $y = -ax$ and, therefore, the slope of the straight line on the $\ln(I/I_0)$ vs. x diagram (Figure 3) will produce the value of the absorption coefficient *μ*, of the material.



**Figure 2:** Diagram of the Intensity of Light Radiation (in arbitrary units) as a function of the thickness of the transparent material (in mm).
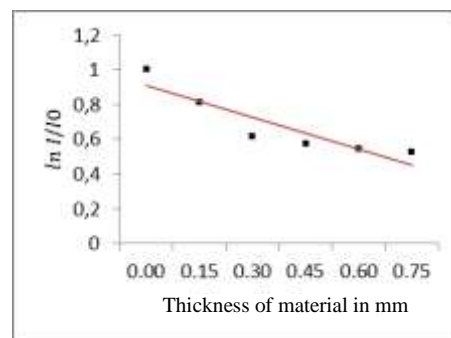
**Figure 3:** Characteristic Curve $\ln(I/I_0)$ vs. x. The slope of the straight line determines the absorption coefficient of the material.

The experiment was completed in two stages. In stage one, we constructed the experimental apparatus which integrates the optical source (LED), the photodiode, the microcontroller (Arduino Uno Rev3)[9] and a servomotor 0-180° (Figure 4).

## 4. THE TECHNOLOGY

The experiment was completed in two stages. In stage one, we constructed the experimental apparatus which

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[8] Taken from author's web site: http://physics.teiath.gr/online_physics/exp/absorption/absorption_exp_proc.pdf
[9] https://www.arduino.cc/en/Main/ArduinoBoardUno

integrates the optical source (LED), the photodiode, the microcontroller (Arduino Uno Rev3) and a servomotor 0-180$^o$ (Figure 4).

Controlling of the servomotor is done by the microcontroller via one of its digital outputs to which the servo is



**Figure 4:** The experimental apparatus. One can observe the Raspberry Pi in the foreground, whereas the Arduino controller placed near the rotating disk.



**Figure 5:** The interface between the device and the user. Screenshot of the experimental procedure.

connected. The intensity values recorded by the photodiode – each time we ask for them- are transferred to the microprocessor by an analogue input of the microcontroller. The microcontroller was programmed in C++ language to receive and send serial data a function supported by the Arduino IDE open-source software, utilized for this purpose.

For the second stage of the experimental analysis, the interface between the apparatus and the user was suitably
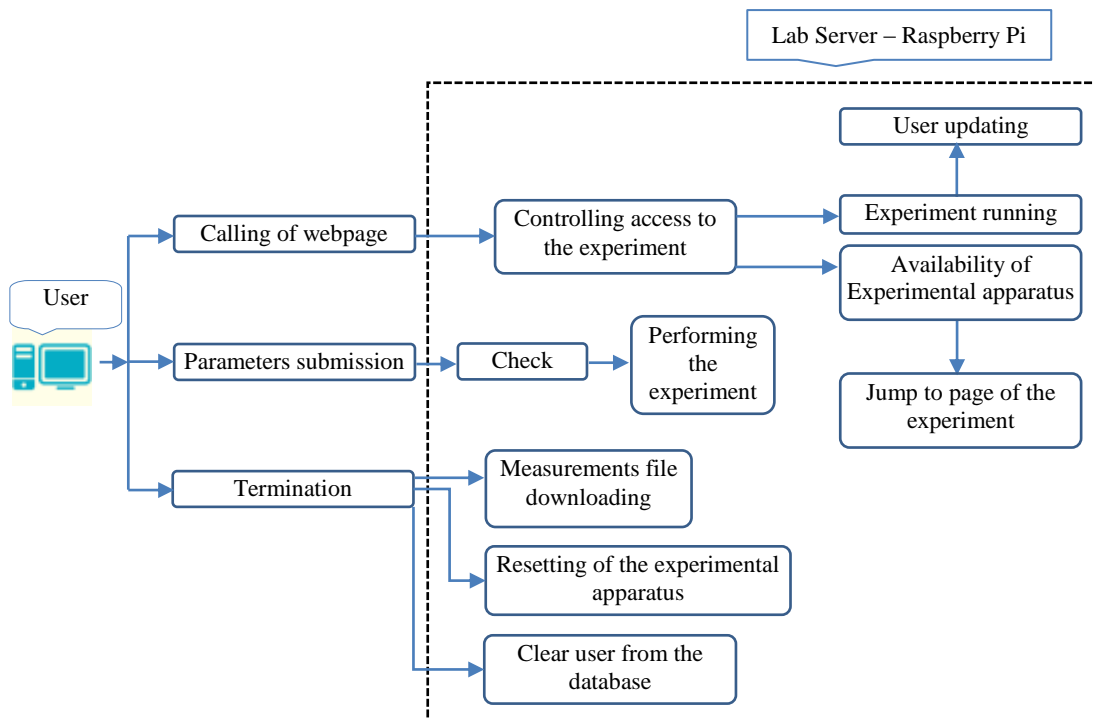


**Figure 6:** System Processes

designed (Figure 5)[10]. This consists of three layers: an html webpage, PHP forms used for entering and reading of the raw

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[10] http://physics.teiath.gr/online_physics/exp/absorption/abs_main.html

data, and finally the software drivers controlling the web camera for the visual monitoring of the experiment. Taking into account that experiments are conducted over the Internet (utilizing a multitude of diverse browsers and operating systems), standard open-source web technologies were specified for the interface design. Any browser capable of executing Java runtime environment could be, thus, utilized. The GUI interface is provided by a web server that displays the html page of the experiment to the user. The server (Apache server) is hosted on a Raspberry Pi computer running a Raspbian operating system, with PHP interpreter and MySQL installed.

The server communicates with the experimental apparatus via the Arduino μ-controller, while PHP modules running on the server operate in two directions: the user's request is passed through the relevant PHP form to the interface of the microcontroller with the experiment where the parameter set by the user is seen as a command and executed by the apparatus. Upon successful completion of the command, the results are sent by the microcontroller to the PHP form, which presents them to the user. The experimental data collected during the procedure are stored on the server in a text file form, which the user can then download for further processing and analysis.

The students, via the html page (Figure 5) are able to carry out the experiment in real-time, where visual monitoring of the experimental setup is provident by a web camera. The interface of the experiment with the user is made up of an entry field, through which numerical values are fed to microcontroller. This, in turn, controls the motor, the rotation of which selects the material thickness. In parallel, a panel appears, where the intensity versus the thickness of the material chart changes dynamically. Also in parallel, live broadcast of the experimental device is been streamed on the net. Finally, a dynamic field that shows the remaining time on a countdown fashion appears. Figure 6 shows all the necessary processes performed during the conduct of the experiment.

## 5. COMMENTS - CONCLUSIONS

The experiment described above is part of an undergraduate optics laboratory, all of which is remotely controlled via Internet and which is in a process of development. An interesting aspect in this project is that a low cost, credit card sized computer, such as the Raspberry Pi is used as a lab server. Its general use in all the experiments of this laboratory changes the situation radically, as it dramatically reduces both development costs and the space required for hosting it. For the time being, only some qualitative research has been carried out as to the way students perceive this novel experimental procedure. Students who used the system recorded similar learning experiences to those who carried out the experiment in the traditional way in the lab. The fact that the web site hosting the experiment was well organized, the relevant theory being very comprehensive, the clarity of the experimental procedure and the tasks to be undertaken by the students helped a lot. Nevertheless, a number of students when facing the task of performing the experiment individually, felt uncertain and were in need of encouragement something revealing a certain lack of self-confidence. This is explained by the fact that they are only used to work in a conventional laboratory in which they work in groups and are thus able to exchange views with their fellow students, covering any knowledge gaps they may have. As a first step to addressing this situation, a chat room could be created on the website of the experiment, where students can ask an instructor for advice and help in real time, thereby building-up confidence. Clearly, this educational aspect or RCL educational usage warrants further research. Such extensive study requires time and resources, and may involve training students how to collaborate effectively, while working on the net.

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