Development of Matlab GUI Educational Software to Assist a Laboratory of Physical Optics

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ABSTRACT

Physical optics is one of the subjects in the Grade of Optics and Optometry in Spanish universities. The students who come to this degree often have difficulties to understand subjects that are related to physics. For this reason, the aim of this work is to develop optics simulation software that provides a virtual laboratory for studying the effects of different aspects of physical optics phenomena. This software can let optical undergraduates simulate many optical systems for a better understanding of the practical competences associated with the theoretical concepts studied in class. This interactive environment unifies the information that brings the manual of the practices, provides the visualization of the physical phenomena and allows users to vary the values of the parameters that come into play to check its effect. So, this virtual tool is the perfect complement to learning more about the practices developed in the laboratory.

This software will be developed through the choices which have the Matlab to generate Graphical User Interfaces or GUIs. A set of knobs, buttons and handles will be included in the GUI's in order to control the parameters of the different physics phenomena. Graphics can also be inserted in the GUIs to show the behavior of such phenomena.

Specifically, by using this software, the student is able to analyze the behaviour of the transmittance and reflectance of the TE and TM modes, the polarized light through of the Malus'Law or degree of polarization.

Keywords: Physical optics; Practices of laboratory; Virtual tool; Teaching methodology

1. INTRODUCTION

The European Higher Education Area (EHEA) has redesigned many of the concepts of the classical education at University. One of the key aspects introduced by the EHEA is the European Credit Transfer and Accumulation System (ECTS)[1], which computes the total student work time taking into account the face activities in the classroom (exams, laboratory activities, etc.) as well as the non-face activities that students must carry out on their own (exam preparation, problem resolutions, etc.). The philosophy of the ECTS has been integrated in the new Degrees by emphasizing the non-face student work as a key element for the Student Centered Learning (SCL)[2-5], which aims an autonomous and active student learning that must be starred by the student both inside and outside the classroom.

The emphasis on the non-face student activities in the EHEA framework together with the implantation of the new Degrees with a total of 240 ECTS[6] has often implied a decrease of the face teaching hours in the classroom with respect to the previously existing system in Spain. Such a decrease in the face teaching hours makes it impossible to maintain a University education entirely focused on the teaching hours imparted by the lecturer, and thus it is necessary to renew the teaching-learning methodology to optimize the available face time in the classroom and to make it as profitable as possible for the students. The need of optimizing the face teaching time is especially remarkable in the block of laboratory practices, in which practice hours are dedicated to making the measurements and in the hours of student work an analysis of these measures is made in order to present the results in the next class.

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Therefore, the student must have an additional material for practices that may be carried outside the lab to finish the data analysis of each practice. For this reason, the creation of a virtual tool can be utility so that students may use it from anywhere with a computer. Specifically, in this paper a series of interactive graphical interfaces will be developed with the program Matlab, which allows to the users insert a set of tables, knobs, buttons and handles in order to check the parameters of the different physics phenomena and a set of graphics to show the behavior of such phenomena. This tool can help students to develop in a comprehensive mode, the practical competences associated with the theoretical concepts studied in class.

These graphical interfaces have been developed considering the laboratory practices of the course of Physical Optics given in the Degree in Optics and Optometry at the University of Alicante (Spain). With this tool it is possible to develop a new methodological approach in the teaching-learning process of laboratory practices which allows increasing the participation of the student and leads to a more complete picture of the phenomenon that is studied.

2. METHODOLOGY

The methodology followed was, firstly, specify what would be the contents included in the subject. Secondly, a series of laboratory practices were devised that were related to the contents of the subject. The experimental development of these practices was designed and implemented in the laboratory classes. And thirdly, an interactive graphical interfaces (GUI) related with the practices were designed and created so that students could complete the data analysis of the practices anywhere with a computer. Furthermore, a simulation environment was added to some of these graphical interfaces in order to show the results obtained with different parameters that could not be measured in the laboratory.

As mentioned in the introduction, the subject for which interactive graphical interfaces were developed was the subject of Physical Optics. This subject is taught in the second semester of 2º course of the Degree in Optics and Optometry at the University of Alicante (Spain) and it has 6 credits ECTS (European Credit Transfer System). At level of hours of actual teaching, this subject has 25 hours of classes of Theory, 15 hours of classes of Problems, 3 hours of Tutorial classes and 17 hours of classes of Practices of Laboratory.

A new model for light based on the wave character of the electromagnetic wave is introduced in the syllabus of the subject so that the energy of a light beam is the energy carried by the electromagnetic wave. Through electromagnetic model the laws of reflection and refraction can not only be deduced, you can get information about the radiant flux densities incident, reflected and transmitted. Furthermore, the electromagnetic model also provides specific knowledge of the physical parameters of the environment that determine the value of its refractive index. Thus the electromagnetic wave model provides a more complete and can explain processes such as light propagation also incorporating aspects of polarization.

The contents are distributed in six chapters which are grouped in three thematic blocks:

I.- ONDULATORY MOVEMENT

Chapter 1. Ondulatory Movement I. Differential wave equation.

Chapter 2. Ondulatory movement II. Superposition of waves.

II.- LIGHT PROPAGATION

Chapter 3. - Electromagnetic theory of light.

Chapter 4. - Reflection and refraction of light in homogeneous and isotropic media.

III. - POLARIZATION

Chapter 5. - Polarization.

Chapter 6. - Obtaining and analysis of polarized light

All this syllabus is taken from different general literature of Optical such as the books[7-10]. Also the information is extracted from literature more specific of Physical Optics, such as the books[11-13].

Related to the theoretical content of the subject the following laboratory practices were designed:

Practice Nº 1: Fresnel Equations-I. Perpendicular component of Reflectance and Transmittance of a interface.

Practice Nº 2: Fresnel Equations-II. Parallel component of Reflectance and Transmittance of a interface. Brewster´s angle.

Practice Nº 3: Effect of polarizers in the light. Malus´s Law.

Practice Nº 4: Polarization by reflection and transmission. Determination of Degree of Polarization.

Practice Nº 5: Quarter-wave plate study: Neutral lines and phase shift.

Practice Nº 6: Obtaining and characterization of different types of polarized light: Determination of Stokes Parameters.

As it can be seen, the first two practices would be included within the Block II of the syllabus associated with the propagation of light in isotropic media and with the demonstration of the Fresnel equations which describe the transmittance and reflectance of light, both in its component perpendicular (Practice 1) and its component parallel (Practice 2). In the practices, the intensity of the light transmitted and reflected by a medium would be measured experimentally in order to calculate the reflectance and the transmittance and the obtained results would be compared with the predictions made by the theoretical model.

The following four practices would be included within the Block III of the syllabus associated with the polarization. Specifically, firstly the Polarization would be defined and the degree of polarization of the light would be studied analyzing as the polarization changes when the light passes through different mediums (Practice 4). Secondly, a polarizer and the effect on light would be defined using the Malus Law (Practice 3). Then it would be studied in more detail the effect on the light of the different devices such as light polarizer and retarder films (Practice 5). And finally the different types of existing light would be characterized by measuring the Stokes parameters (Practice 6).

These six practices are held for six sessions of 2.5 hours which makes a total of 15 hours. To complete the 17 hours that correspond, at the seventh session, which lasts for 2 hours, students must make a written exam with questions about the lab practices.

3. RESULTS

This section presents a summary of the objectives to be achieved in each practice and a brief description of the theoretical basis underlying the phenomenon that it is present in every one. This will be necessary to understand the procedure followed in the preparation of the interactive graphic interface created with Matlab (GUI) in each one of the practices, as virtual tool. They have enabled students obtaining the final results of the practices in an efficient way.

3.1 Practice 1 and 2: Fresnel Equations. Parallel and Perpendicular components of the Reflectance and Transmittance of a interface

The main objective of the practice 1 is determined experimentally the component perpendicular to the plane of incidence of the reflectance and transmittance of an interface and compare them with the theoretical reflectance and transmittance deduced from the Fresnel equations. In the case of the practice 2, the objective is to experimentally determine the component parallel to the plane of incidence of the reflectance and transmittance for the same interface of practice 1, and compare the obtained results with those deduced from the Fresnel equations. In addition, in this practice 2, also it is possible to determine Brewster's angle what is the angle at which the reflected intensity is zero. The importance of measuring the Brewster's angle is that the refractive index of the material could be calculated from it.

To experimentally determine the reflectance and transmittance in both practices firstly an experimental setup should be designed for this purpose. A light beam expanded and collimated from an He-Ne laser fall on a medium having a black coating on its back face in order to obtain only the reflected intensity in the first air- medium interface. To obtain precisely the proper polarization, the beam was passed through a polarizer with its transmission axis vertical (practice 1) or horizontal (practice 2) to obtain the perpendicular or parallel respectively components to the plane of incidence of the reflectance, R, and the transmittance, T. Students should measure in both practices the reflected intensity by the medium, the background or dark intensity and the incident intensity for different angles of incidence.

Figure 1 represents the screenshoot corresponding to the GUI created to Practices 1 and 2.

On the left of figure 1 it is located a part where theoretical reflectance and transmittance for perpendicular and parallel components can be simulated depending on the angle of incidence. The parameters to be entered for the simulation are the refractive indices of incident and transmitted medium. After insert the refractive indices and press the button "Plot" both graphs are drawn above.

In the middle of Figure 1 the experimental data inserted by the student once made the measurements of the reflected intensities, background and incident are drawn.

And on the right side of Figure 1 are, from top to bottom, the following elements: two tables in which the students must insert for each angle of incidence, the measurements of the reflected intensity, the incident intensity and background intensity, for the perpendicular component (Practice 1) and for the parallel component (Practice 2). Below are two buttons "Plot" that when they were pressed the experimental data introduced in the tables would be drawn. And finally, at the bottom right, there is a part for calculating the Brewster's angle (corresponding to Practice 2), in which the student has to introduce the Brewster's angle measured experimentally and to press the button "Calculate". Then, the GUI provides the numerical value of the refractive index of the material.

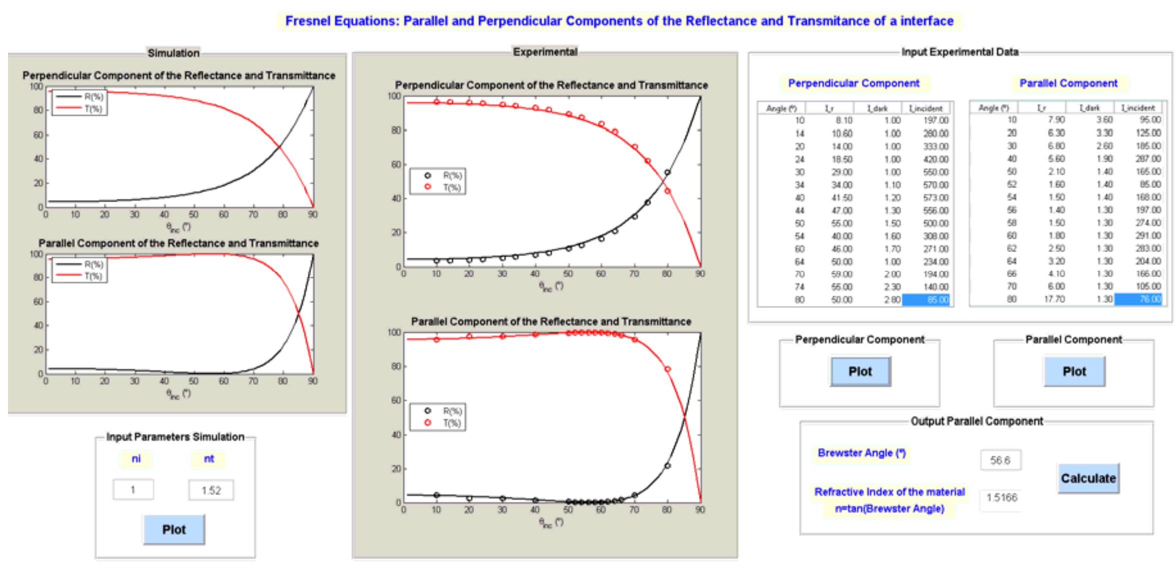

Figure 1. Screenshot of the interactive graphic interface corresponding to the practices 1 and 2.

3.2 Practice 3: Effect of polarizers in the light. Malus´s Law.

The objective of the practice 3 is prove that when linearly polarized light impinge on a polarizer, the irradiance that emerges depends on the angle between the direction of vibration of the incident electric field with the direction of transmission axis of the polarizer. In this sense it is found experimentally that meets Malus Law when light passes through two or three polarizers.

The experimental setup of this practice is the following: a collimated natural light beam is generated by a white light source, a lens and a pinhole which is collocated at the focal distance of the lens. This collimated beam fall on one polarizer in the first part of the practice, two polarizers in the second part and three polarizers in the third part.

Figure 2 represents the screenshoot corresponding to the GUI created to Practice 3.

When a natural light beam impinge on a polarizer, irrespective of its transmission axes, at the output of the polarizer is obtained half of the incident light. This first part of the practice 3 is shown on the left side of figure 2 (unpolarized light through one polarizer). Students have to measure the intensity of light that is obtained when the natural light passes through a polarizer for different orientations of the polarizer transmission axis and the incident intensity. Once measured, the values obtained are inserted in the table on the left with the value of the incident intensity (I_{MAX}), and pressing the button "Plot", the experimental values with the theoretical curve is represented in the graph on the left.

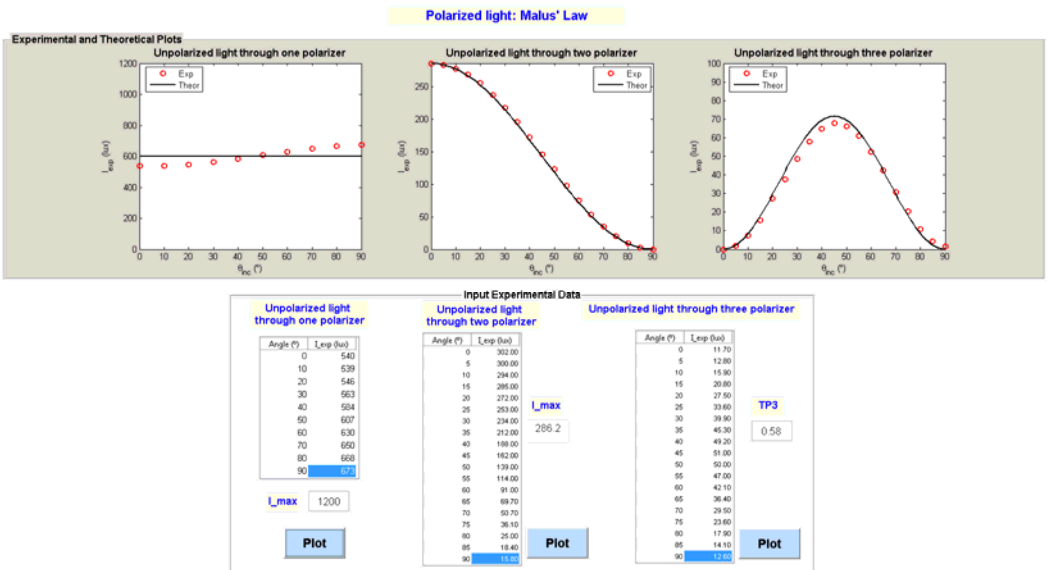

Figure 2. Screenshot of the interactive graphic interface corresponding to the practice 3.

In the central part of figure 2 the second part of the practice 3 is shown (Unpolarized light through two polarizer). When natural light beam passed through the first polarizer, linearly polarized light is obtained. The first polarizer is kept fixed in a given position while the second polarizer is rotated. A maximum irradiance is found when the transmission axes of the two polarizers are parallel and a null irradiance is found when the transmission axes are perpendicular to each other. Students must measure the irradiance at the output of the two polarizers for different orientations of the transmission axes of the second polarizer, keeping fixed the orientation of the first polarizer. The values are inserted in the table corresponding to this section, and then the button "Plot" is pressed. In the central graph, experimental values introduced in table and the theoretical curve corresponding to the irradiance which was calculated from the Malus's Law are drawn:

$$I = I_{MAX} \cos^2 \theta \qquad (1)$$

where I_{MAX} represents the emergent irradiance when the transmission axes of the polarizers are parallel, and the angle θ is the angle formed by the transmission axes of the two polarizers when the orientation of the axes of the one of them is changed.

On the right of Figure 2 the third part of the practice is represented (Unpolarized light through three polarizer). At the setup for this third part, the natural light beam pass through three polarizers. The transmission axes of the first and the last polarizers are placed perpendicular to each other, so the light does not pass through them. Placing a polarizer in the middle, light can be obtained at the output, if it is properly oriented. So the students must rotate the orientation of the polarizer placed in the middle and measure the irradiance obtained at the output of the system. The transmission of the polarizer located in the third place must be measured too. The irradiances obtained are introduced in the corresponding table with the value of the transmission of the third polarizer (TP3) and when the button "Plot" is pressed the graphic above represents the experimental points and the theoretical irradiance obtained applying in this case the Malus's Law twice:

$$I = I_{MAX} \cos^2 \theta \cos^2 (90 - \theta) \tag{2}$$

where generates a Gaussian curve.

3.3 Practice 4: Polarization by reflection and transmission. Determination of Degree of Polarization.

The objective of the practice 4 is to determine the degree of polarization of the transmitted light on a layer of glass and check that the degree of polarization increases as the number of layers.

The experimental design of this practice is the following: a collimated natural light beam from a white light source fall on a different number of glass layers with the Brewster´s angle, and a reflected and a transmitted beam is obtained. The transmitted beam is passed through a polarizer with a horizontal and vertical orientation of the transmission axes, and the irradiance at the output of the system is measured for the different number of the glass layers.

Figure 3 represents the screenshoot corresponding to the GUI created to Practice 4.

On the left of figure 3 the simulation of the degree of polarization is represented versus the number of glass layers. The input parameter for the simulation is the number of layers and the students can see how the theoretical degree of polarization change varying this number layers.

On the right of figure 3 there are a table where students must enter the irradiance values obtained for different numbers of blades. An additional column shows the values of the degree of polarization. In addition, the student is prompted for a parameter called "Correction Factor". This parameter is the relationship between the measured irradiance with a horizontal orientation of the transmission axes and with the vertical orientation. When the button "Plot" is pressed the graphic above represents the experimental points and the theoretical degree of polarization.

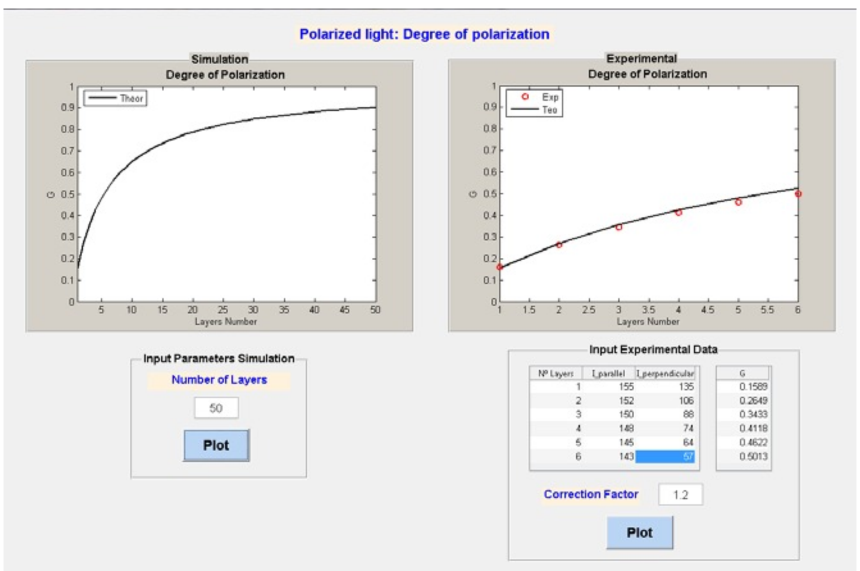

Figure 3. Screenshot of the interactive graphic interface corresponding to the practice 4.

4. CONCLUSIONS

In this work a optics simulation software that provides a virtual laboratory for studying the effects of different aspects of physical optics phenomena has been developed. This software let to the students simulate optical systems related with the laboratory practices of the subject Physical Optics. This interactive environment has been developed through the choices which have the Matlab to generate Graphical User Interfaces or GUIs. A set of knobs, buttons and handles will be included in the GUI's in order to control the parameters of the different physics phenomena. Graphics can also be inserted in the GUIs to show the behavior of such phenomena. At the moment, the software of four of the six practices has been developed: Fresnel Equations: Parallel and Perpendicular components of the Reflectance and Transmittance of a interface, Effect of polarizers in the light: Malus´s Law and Polarization by transmission: Determination of Degree of Polarization. In a near future, the GUIs of the other practices will also be developed.

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