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A laboratory of image processing and holography for physics students

M. J. Yzuel , J. C. Escalera, A. Lizana, M. Espínola, and J. Campos.

Departamento de Física, Universidad Autónoma de Barcelona, 08193 Bellaterra, Spain.
+(34)935811933, *maria.yzuel@uab.es*

Abstract: In the Physics degree in Spain the students have a mandatory course in Fundamentals of Optics as well as an Optics Laboratory course. With these two courses the students receive a general background of optics. There are also some optional courses on Optics in the last years of the degree. One of them is a course on Optical Image Processing and Holography. This course has 60 hours (equivalent to 6 credits of a total number of 300 credits in the Physics degree). Fifteen hours of the course correspond to the laboratory experiments. In this contribution we will describe the contents of this laboratory experiments and we will also discuss the influence of this laboratory in the background of a physicist. The laboratory works consist of three lab experiments about the following topics: Diffraction, Coherent Spatial Frequency Optical Filtering and Holography. Optical Image Processing and Holography course survey of students' opinion is presented to analyze different pedagogical aspects.
Keywords: Diffraction, Image Processing, Spatial Frequency Optical Filtering, Holography.

1. Introduction

The Physics degree in Spain lasts in general 5 years. There is a course of Fundamental of Optics in the second or third year. The topics studied in this course include: geometrical optics, wave optics, interferometry, diffraction, polarization, etc. The students have the chance to follow several optional courses related to Optics. One of them is a course on Optical Image Processing and Holography (OIPH).

The OIPH course not only provides them a theoretical knowledge, but also an experimental one, since 15 hours (the course lasts 60 hours) correspond to the laboratory experiments. This way, an experimental understanding reinforces the theoretical knowledge learned at the classroom, let us say in the theoretical lectures. The laboratory practices are made in groups of a maximum of three people. Therefore, the teacher can focus his effort in a small number of students, becoming a more individual training and promoting a teacher-student interaction that leads to a better level of understanding. Furthermore, by means of the delivery of a questionnaire about the experiment, the teacher sets a guideline that allows students to know the fundamental points of the experiment. In addition, these questionnaires help students to do a constant work and consolidate the knowledge they have learned. These questionnaires and a mandatory report (about one of these three experiments) are evaluated and have a specific weight in the final course mark. All this, plus a final theoretical exam gives the final mark, and one of the questions of the final exam refers to the work done in the laboratory. Therefore, it is especially important to pay attention in the three lab sessions in order to achieve a good mark.

The theoretical course has mainly three key lines, giving a solid mathematical base in Diffraction, Optical Filtering and Holography. In the lab, three experiments are made, showing a new vision of mathematical concepts through real phenomena and students are initiated into the laboratory process complexity. These experiments, in addition to the theoretical fundamentals taught in the course, allow the study of particular phenomena in both quantitative and qualitative ways.

Before the students go to the lab, the topics have been studied in the theoretical lectures. An explanatory text for each experiment is also given in advance to the students. It contains the guidelines to make the lab work. Besides a lab teacher is with the students to help them along the experiment. After the experimental works, the students present four lab reports: 3 short questionnaires, one for each experiment and one more detailed report about one of them. We have surveyed all students of the (OIPH) course (2006-2007) to obtain a feed-back of information.

The survey analyzes several pedagogical aspects: importance of the theoretical and experimental classes, quality of the guidelines, importance of the lab teacher, etc.
The introduction of the course in the Physics studies permits to train the students in the fundamentals of the general theory of Signal Processing. Although the dimension (two dimensions / one dimension) and the magnitude (spatial / temporal) of the signal are different, the mathematical fundamentals are analogous.

In sections 2, 3 and 4 we show the aim of the three experiments and describe their usefulness in students training. In section 5 we show the statistical results of (OIPH) course survey of students' opinion. Finally, in section 6 we summarize the work.

2. Fraunhofer's diffraction

In this experiment, the Fraunhofer's diffraction is studied [1-3]. The students observe, capture with a CCD camera and a frame-grabber and measure the diffraction made by several apertures. The set-up used (fig. 1) allows not only a qualitative and quantitative study of the diffractive phenomena, but also lets us know properties of several typical laboratories elements, as spatial filter, lens, laser, CCD camera and so on. Moreover, this experience shows clearly the relationship between the object space and the Fourier plane in a visual way. In fact, regarding to diffraction patterns, in this experiment the student watch the Fourier transform for slits with different shapes, double slits, one-dimensional and two-dimensional arrays, and in each case, the teacher gives a detailed mathematical formulation. Some experimental results obtained by the students are shown in fig. 2.

Furthermore, this experiment is also useful to introduce students to metrology relations. Measures are made upon the images captured by means of the CCD camera placed on the detector plane (fig. 1), and students have to seek out the relationship between distances in millimeters in the focal plane and the pixels in the digital image. To perform the calibration a grating is used in the aperture plane. Then, in the detector plane several bright spots corresponding to the different diffraction orders of the grating are obtained (fig. 2d). The distance between several spots is measured firstly with a calibrated ruler to determine the distance in millimeters. Then, this pattern is captured with the CCD camera and the distance in pixels is measured with the software written for this experiment. This software permits the capture of images and its analysis, distance measures, intensity graphs, etc. Moreover, the theoretical diffraction image can also be calculated and a comparison between experiments and theory can be performed.

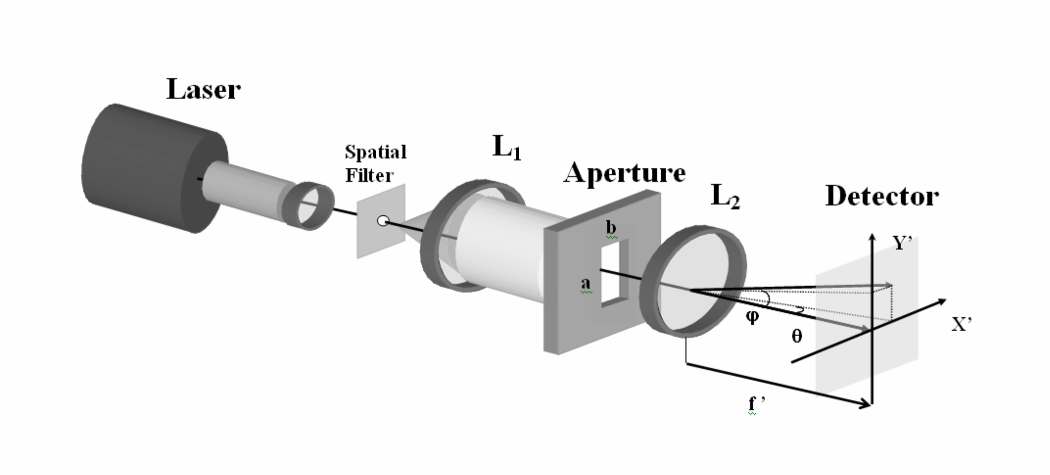
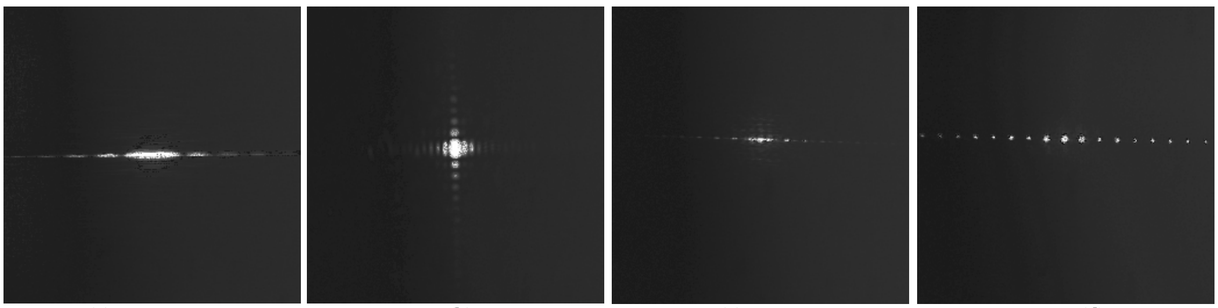


Fig. 1. Fraunhofer's diffraction experimental set-up.

The diffraction patterns studied in this experiment are produced by the following apertures:

- Slit aperture. The distance between the minima is measured (see fig. 2-a) and the width of the slit is evaluated. The diffraction produced by a complementary aperture is also studied.
- Rectangular aperture. The distance between the minima in two axis is measured (see fig. 2-b), and the width and height of the aperture is evaluated.
- Circular aperture. The radius of the central disk of the diffraction pattern is measured. The radius of the circular aperture is evaluated.
- Double aperture (two rectangles). The distance between the interference minima is measured (see fig. 2-c). The distance between the two apertures is evaluated.
- One-dimensional array. Diffraction patterns of gratings with different numbers of slits from 3 to 6 are studied. The diffraction produced by a grating is also studied (see fig. 2-d). The distance between the principal maximum is measured, to obtain the distance between the slits.
- Different types of two-dimensional arrays: a rectangular array of circular apertures contained within a circular aperture, hexagonal array of circular apertures, etc.



(a) (b) (c) (d)

Fig. 2. Experimental Fraunhofer's diffraction patterns captured by the students.
a) slit aperture, b) rectangular aperture, c) double slit aperture, d) one-dimensional array.

3. Coherent spatial frequency optical filtering

This experiment has mainly two aims. On one hand, we look for a visualization of the spatial frequencies contents in several images and on the other hand, we want to produce modifications in the spectral content (coherent optical filtering) [4-6]. In this last case, we want to see its effect in the final image. For that reason, we use a correlator that allows us to obtain and see the Fraunhofer's diffraction of a scene, as well as its filtering process and the final image.

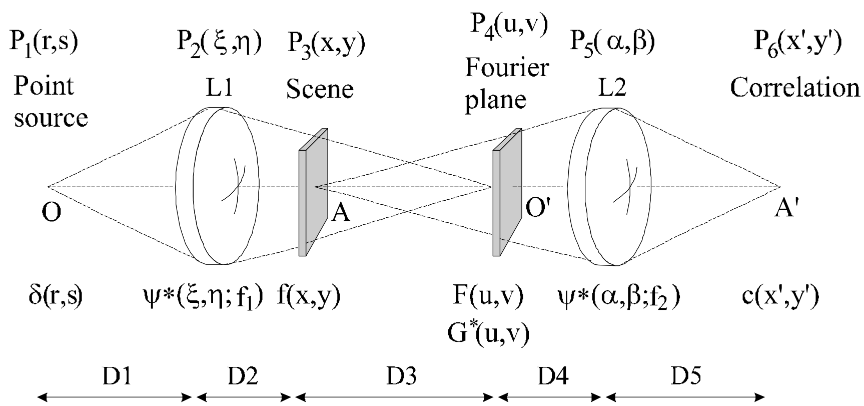


Fig. 3. Geometry of the optical convergent correlator. L_1 and L_2 are convergent lenses.
O´ is the image of O given by L_1, and A´ is the image of A given by L_2.

Fig. 3 shows a convergent correlator [6,7]. The lens L_1 generates a convergent wave and makes in O' the image of the point source O. By inserting a transparence with a transmission f(x,y) just after the lens L_1, we obtain a complex amplitude F(u,v) in the Fourier plane. F(u,v) is the Fourier Transform of f(x,y) multiplied by some constant values and an exponential term. The second lens L_2 produces an image of the scene in the correlation plane A'.
In order to lead students into a better understanding, we have made several improvements [7] to the typical convergent correlator as we show in figure 4. In fact, we have introduced a spatial filter and a perpendicular arm that projects, through the lens L3, the Fourier plane image, let us say F(u,v), in the screen.

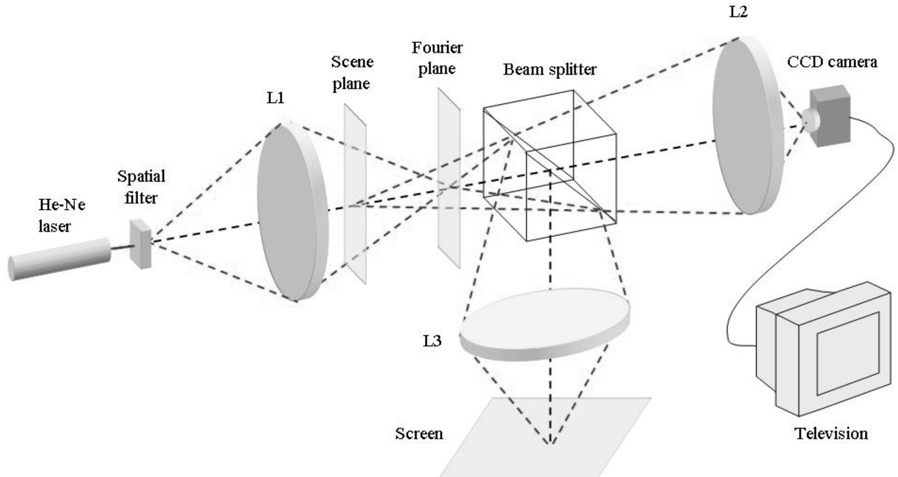
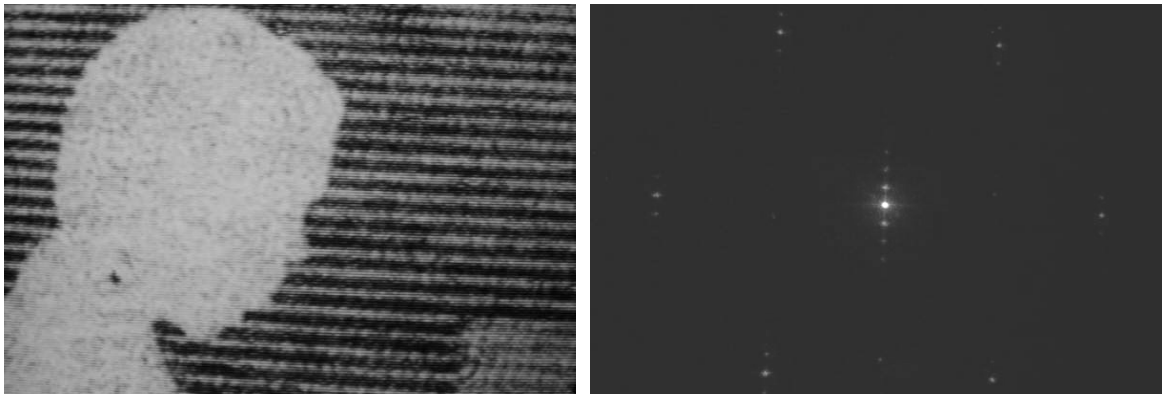


Fig. 4. Experimental set-up: convergent optical correlator with two arms.

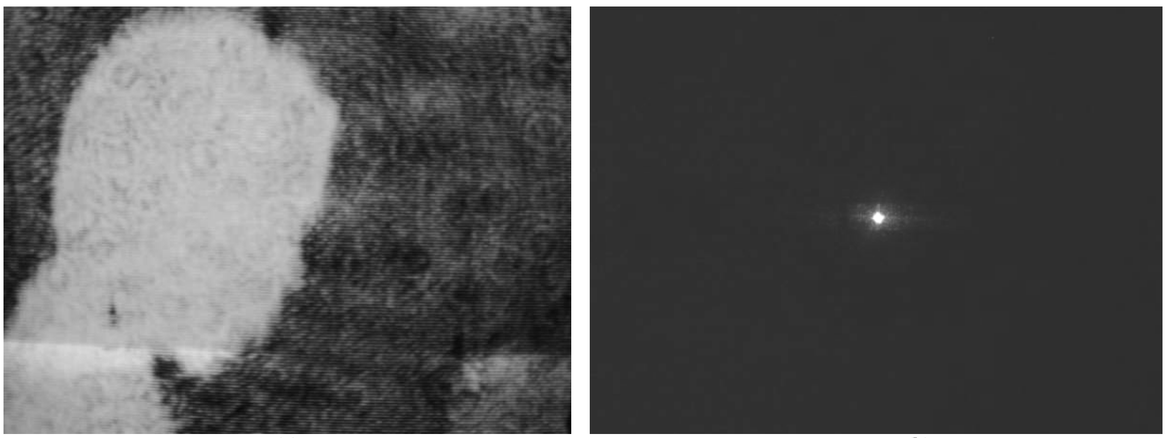
By means of this device, the students can see at the same time the Fourier plane in a screen and the final image, captured by a CCD camera, displayed in a television set. Therefore, it is very interesting the point that students, by making some changes on the Fourier plane, can see the modifications on the Fourier plane and on the final image. Moreover, by changing the distance D3 they are able to observe directly the variations in the scale of the Fourier transformation of a scene, and by using filters in the Fourier's plane, they can directly realize that the final image only contains the frequencies which the filters let pass through. We also think that using a digital camera connected with a television, students notice the important role that technology plays in Optical Signal Processing.

We show some images captured by the students in the following figures. Each group of graphs shows the original image and its Fourier Transform (FT), and the filtered image alongside with the manipulated Fourier Transform. Fig.5-a shows a scene with a face and a blind (parallel bars) background. This photograph has been taken from a computer monitor. Fig. 5-b shows its Fourier Transform. The hexagonal periodicity in the diffraction orders is due to the hexagonal distribution of the pixels in the monitor we used. The filtered image is showed in fig. 6-a. In this case a horizontal slit has been used to filter the image, removing the bar background (fig. 6-b). Another example is shown in fig. 7. In this case, the scene is a two dimensional rectangular array of circles (fig. 7-a). The Fourier Transform of this scene is shown in fig. 7-b. We will show two different manipulations of the image. First, we can see in fig. 8 that the scene is transformed in a set of horizontal bars when the FT is filtered with a vertical slit. Secondly, we can see in figure 9 that the scene is transformed in a set of vertical bars when the FT is filtered with a horizontal slit.



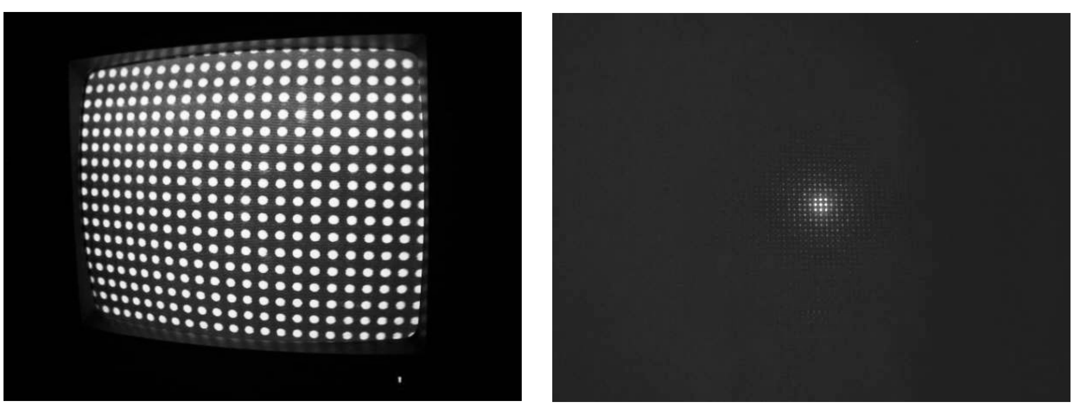
(a) (b)

Fig. 5. a) original scene, b) diffraction pattern (Fourier Transform).



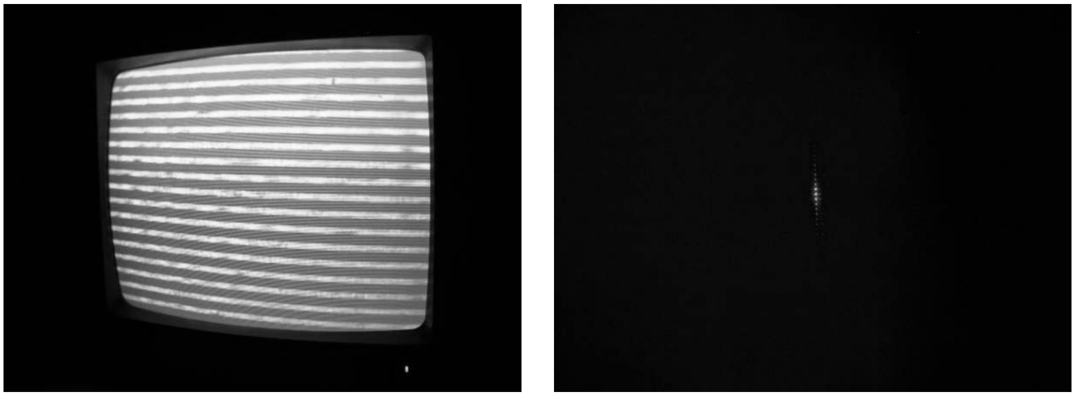
(a) (b)

Fig. 6. a) filtered image, b) diffraction pattern (Fourier Transform) filtered with an horizontal slit.



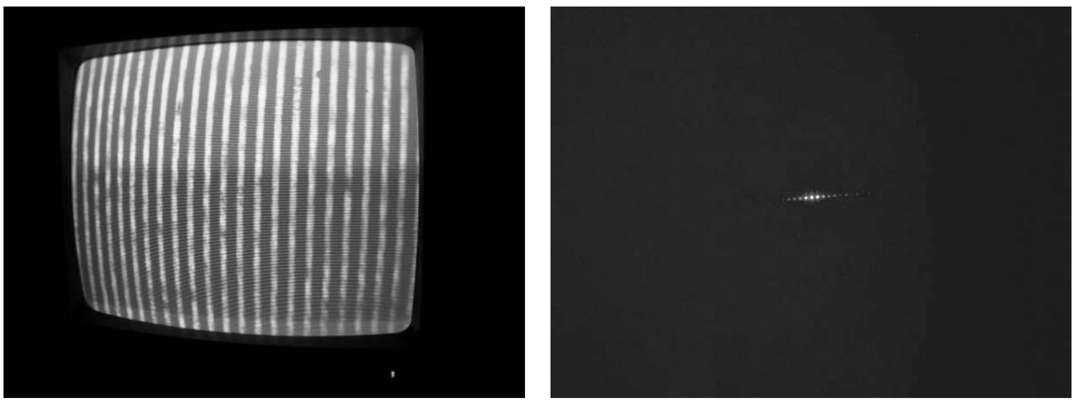
(a) (b)

Fig. 7. a) scene, b) diffraction pattern (Fourier Transform).



(a) (b)

Fig. 8. a) filtered image, b) diffraction pattern (Fourier Transform) filtered with a vertical slit.



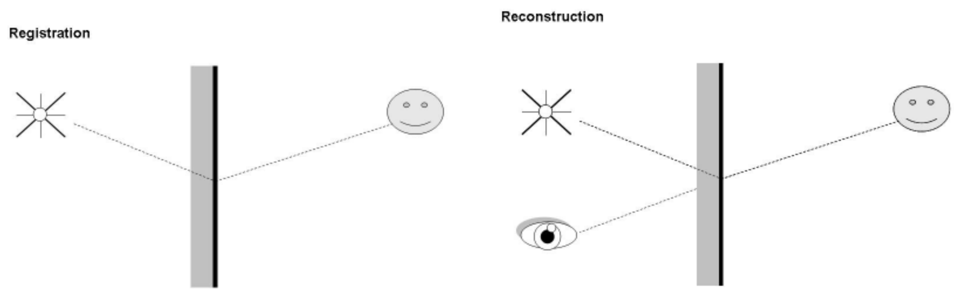
(a) (b)

Fig. 9. a) filtered image, b) diffraction pattern (Fourier Transform) filtered with an horizontal slit.

4. – Holography

In this experiment, students approach the holography as a particular case of interferential phenomena. In the theoretical lessons, students learn different holographic methods and in the lab the students work with different type of holograms to reconstruct the image [8-12] . With transmission holograms they observe the virtual and real image. They can observe that each point of the hologram keep information of the entire scene. This property can be observed if we obtain the reconstruction of the real image by illuminating directly with the laser in a very small area. Different types of rainbow holograms are also observed in the lab, for instance, as security method in credit cards, currency, bank notes, etc.

Each group of students makes several Denisyuk's reflection holograms. Now, we will describe the whole process with a little more of detail. In a reflection hologram, the light diffused by the object and the light of the reference wave arrive to the two opposite faces of the holographic plate. In order to visualize the object image, the observer has to locate himself at the opposite place of the object, and therefore at the same place where the reference wave source is set. The object image is made by the light reflected by the hologram.



(a) (b)

Fig. 10. Reflexion hologram. a) Registration, b) Reconstruction.

Next, in figure 11 we show the experimental set-up. With this set-up for reflexion holograms the students could make amplitude holograms or phase holograms but the techniques used for the developing in laboratory correspond to a phase hologram. Therefore in this experiment a phase hologram is made by students. The set-up is on a vibration isolating optical table and a He-Ne (633nm) laser is used. The laser beam is expanded by means of a spatial filter and reflected by two mirrors. Finally the beam passes through the holography plate (Agfa-Gevaert 8E75HD) and reaches the object, where the light is diffused. The interference is produced between the wave diffused by the object and the wave which comes directly from the laser. In darkness conditions, the holographic plate is set in its set-up place with the emulsion at the object side. By means of the use of an electronic shutter we adjust the exposition time.

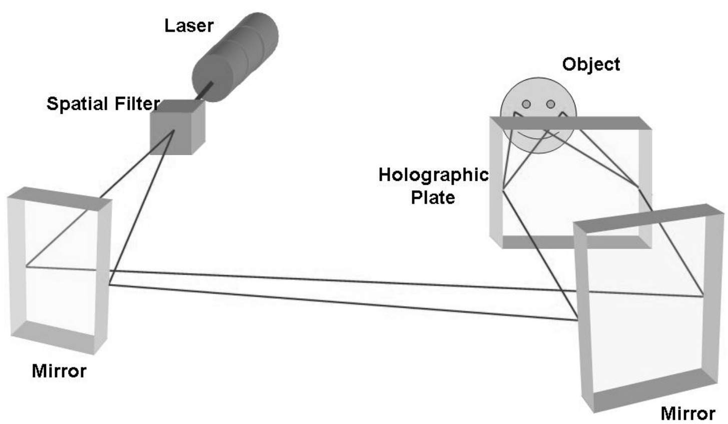


Fig. 11. Holographic experimental set-up. Denisyuk's configuration.

In addition, this experiment allows students to make acquainted with developing material for the first time in the physics degree. In fact, they have to use a developer, stop liquid (water) and bleaching liquid, and do the different steps required to obtain a hologram. Beside, this experiment also stimulates the teamwork because the students have to help themselves in the registration of the hologram and in the developing process.

Specifically, the developing is made with the next materials and steps:

- Developer D-19 4 minutes (1 minute shaking the container where the plate is immersed in the liquid and later the shaking is in intervals of 30 seconds).

- Stop liquid (water) 1 minutes shaking.

- Bleaching liquid — until the holographic plate turns transparent plus one minute more.
- Washing in water — 10 minutes without shaking.
- Drying — 1 day in ambient temperature and in darkness conditions.

5. OIPH course survey of students' opinion

In this section we show the results of a survey of students' opinion that we have done with the students of the Optical Image Processing and Holography (OIPH) course. The questionnaire has been answered anonymously by all of the 15 students of the course at the end of the final exam (Feb. 2007). The questionnaire we have given to the students in order to make the survey is as follows:

Evaluate from 1 to 5 the following questions:

1) Mark the influence in your degree of knowledge satisfaction made by theoretical and experimental classes:

	Theoretical classes	Experimental classes
Diffraction	☐	☐
Optical Filtering	☐	☐
Holography	☐	☐

2) Do you think lab experiments have helped you to be aware of the mathematical fundamentals taught in the theory lectures?
3) Do you think OIPH has assisted you to consolidate concepts previously studied in the mandatory General Optics course?
4) Are the questionnaires given in the lab experiments useful to do the lab experiments and become conscious of their theoretical base?
5) Do you find helpful the assistance of the laboratory teacher to do the experiments?
6) Do you think OIPH has provided you a higher knowledge about how the research is made in the research laboratories?
7) Has OIPH helped you to make acquainted yourself with optical laboratory typical elements?
8) Have the experiments done in the lab been useful to obtain better marks in the final exam?
9) Do you assume questionnaires and reports value in the final mark (12,5%) are suppose to be enough?

In figures 12 and 13 the results of the survey are shown.

Fig. 12 shows that the students value positively (more than 3 over 5) the theoretical lectures as a source of knowledge for the three topics (Diffraction, Optical Filtering and Holography). Nevertheless, they are even more satisfied with the experimental classes (more than 4 over 5).

Fig. 13 shows an average of the students answers to the items 2 to 9. We observe that all the items except item 9 receive very positive scores. Item 2 receives a very high score (4.6 over 5) that shows that the experimental classes have been very helpful to fully understand the mathematical fundamentals of the topics studied. Item 3 obtains a good score (3.9 over 5) showing that the lab experiments help them to consolidate concepts studied in the General Optics course. Probably, the score would be higher if the lab classes would cover more topics of Optics, but this aspect was not studied in the survey. Item 4 is scored positively (3.4 over 5) but less than other items. This suggests that the guidelines to the experiments are useful but maybe they are not enough to properly make the experiments. This is probably the reason why the students value very positively the help from the lab teacher in item 5 (4.3 over 5). Items 6 (3.7 over 5) and 7 (3.7 over

5) show that students feel that their knowledge about lab research and optical devices has improved. Interestingly, the students think that their final mark has been better because of the experimental classes (item 8: 4.1 over 5). Probably there are two reasons. Firstly, one third of their final exam includes questions about the lab experiments. This good score suggests that the concepts studied in the lab were well learned and consequently it improved the result on the final exam. Secondly, the lab questionnaires and reports that they present have a weight of 12.5% on the final mark. Item 9 clearly states that the students feel that the lab reports should have a higher weight on their final mark.

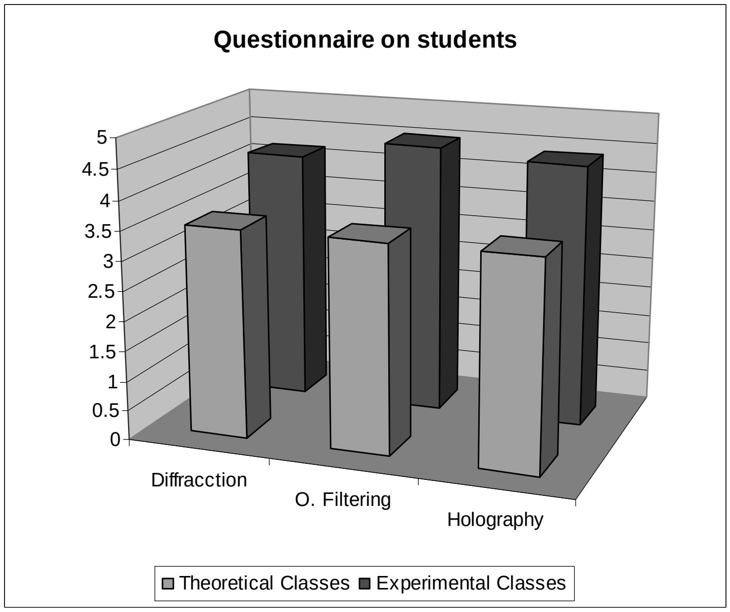


Fig. 12. Students' satisfaction degree (0 to 5) on the knowledge of the three topics related to the theoretical and experimental classes (item 1).

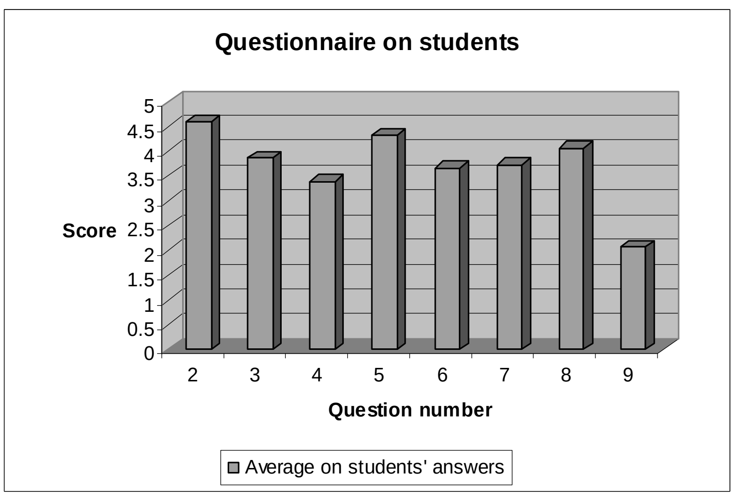


Fig. 13. Student's satisfaction degree (0 to 5) on the items 2 to 9 of the survey.

6. Summary

We describe the three experiments that the students make in the lab during the course of Optical Image Processing and Holography in the Physics degree. The experiments are: Diffraction, Coherent Spatial Frequency Optical Filtering and Holography. We also describe the way the students make the experiments and how they are evaluated. The students of the course have fulfilled a questionnaire about pedagogical aspects of the subject just after the final exam. We have used this survey to discuss the influence of the laboratory in the background of a physicist.

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