Learning about light properties using a system for optical signal processing

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Abstract

To learn and manipulate the wave nature of light, for purpose of teaching, we designed and set up an optical communication system using low cost laser diodes and multiplexing holograms. Making use of the wave nature of light, different kind of information could be send using different wavelengths appropriated to perform a multiplexing effect. By making several beams of light, each modulated in amplitude by dissimilar analogical or digital signals, to impinge simultaneously on a holographic grid, which send the beams thorough some kind of waveguide that can be an optical fiber. At the output where information was received, a similar grid was used to separate the different information carriers, each being addressed towards different corresponding photo detectors for demodulating the desired information. Modulation of laser light was realized by standard simple electrical circuits, which bring out different kind of information. For example, audio signals, radio transmitters, cell phones, portative sound reproducers. In addition, by simple standard circuits for the photo detectors we could convert intensity light variations into electrical signal differences, for each wavelength, which lead to the final information retrieval using corresponding transducers, as loudspeakers, which is the final stage for the information originally sent throughout optical signal variations. The proposed method was tested with a 17 students with favorable results, encouraging the authors for designing new experiments with the same idea of making a more dynamical active learning to help the students to develop new skills and more effective training in optical engineering and applications.

Keywords: Optical communication, Nature wave of light, Laser.

Abstract

Con propósito de enseñanza, hemos diseñado y creado un sistema de comunicación óptica, utilizando diodos láser de bajo coste y hologramas de multiplexación, para aprender y manipular la naturaleza ondulatoria de la luz. Haciendo uso de la naturaleza ondulatoria de la luz, diferentes tipos de información se podrían enviar usando diferentes longitudes de onda apropiada para realizar un efecto de multiplexación. Al hacer varios haces de luz, cada uno modulado en amplitud por señales analógicas o digitales diferentes, que inciden simultáneamente sobre una rejilla holográfica, que envían las haces mediante algún tipo de guía de ondas que puede ser una fibra óptica. En la salida donde se recibió información, una rejilla similar se utilizó para separar los diferentes soportes de información, cada uno dirigido hacia diferentes fotodetectores correspondientes a la demodulación de la información deseada. La modulación de la luz láser se realizó por medio de circuitos eléctricos simples estándar que llevan a cabo diferentes tipos de información; por ejemplo: señales de audio, transmisores de radio, teléfonos celulares, reproductores portátiles de sonido. Además, con circuitos estándar simples para los fotodetectores, podríamos convertir las variaciones de intensidad de luz en diferencias de señal eléctrica, para cada longitud de onda, que conduzcan a la recuperación de la información final, utilizando los transductores correspondientes, como altavoces. Esa es la etapa final de la información enviada originalmente, a través de variaciones de la señal óptica. El método propuesto se probó con unos diecisiete estudiantes, con resultados favorables. Esto animó a los autores al diseño de nuevos experimentos, con la misma idea de hacer un aprendizaje activo más dinámico, para ayudar a los estudiantes a desarrollar nuevas habilidades y una formación más eficaz en la ingeniería óptica y aplicaciones.

Palabras clave: Comunicación óptica, Naturaleza ondulatoria de la luz, Láser.

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I. APPARATUS DESIGN

Compared with existing techniques for electronic methods [1], multiplexing and de-multiplexing by wavelength division, using holograms allows transmitting a bigger volume of information with more speed.

An optical communications system consists of three blocks as shown schematically in figure 1. The transmitting section involves the multiplexing, the middle section corresponds to the transmitting medium and the reception section is where de-multiplexing takes place.

Multiplexing consists in making those different wavelength λ_j laser beams, each modulated by different analogical or digital signals, to coincide on the hologram. The function of the hologram is to superpose the incident wavelengths all coupled simultaneously thorough the optical fiber for sending all the information together.

In receptive section, an identical hologram to the one used for multiplexing splits (de-multiplexes) the different λ_i which carry the information and make them to inside on corresponding photo-detectors thus allowing to decode the information in each channel.

With the purpose of illustrating the use of the wave properties of light to transmit simultaneous information, using different wave lengths; we created special holograms, that bears optical multiplex, de-multiplex properties. The design, fabrication, testing, correction and adjusting of the components in such system, open up the understanding of the properties of light, its interaction with materials in search of new applications.

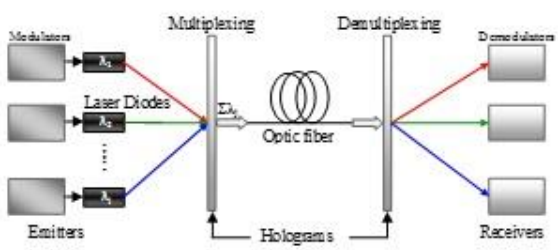

FIGURE 1. Block diagram of a optical communication system.

II. THEORY

According to the holographic principles [2], to record a hologram, as in figure 2.a), two coherent beams –which come from the same source, with wavelength λ_r – are needed.

These two beams are knows as: object beam *Eo* and reference beam *Er*.

If the object is in direction normal to the hologram plane and the reference beam makes an angle Θ_r with the normal to the hologram plane, the information coming from the object beam is stored in the interference pattern of both beams: the hologram of the object. When the hologram is illuminated with the same reference beam, as in figure 2.b), by diffraction several beams come out, among them a normal beam to the hologram plane, as it was the continuation of the original beam used when the hologram was recorded. See Figure 3.

If in the supposition above two plane waves are used as object and reference beams, the interference pattern consists of parallel fringes with separation $\frac{\lambda_r}{\sin\theta_r}$, as it is shown in Figure 3.

The same pattern of fringes can be obtained using different wavelengths at different angles, according to the following relation:

$$\frac{\lambda_j}{\sin\theta_j} = \frac{\lambda_r}{\sin\theta_r} \tag{1}$$

Where λ_j is the new wavelength, and Θ_j the corresponding angle.

This means that, if after the hologram is processed, we make to impinge simultaneously on the hologram, different reference beams λ_j, at reference angles Θ_j, according to (1): on the back of the hologram, transposed object beams of different colors appear in direction normal to the hologram plane. Letting in this way the optical multiplexing of the wavelengths λ_r; each one of them carrying different signals information.

Based in the principle of reversibility of light we can separate the multiplexed beams with the aid of a second hologram identical to the first, which works as a de-multiplexing of signals. See figure 4.

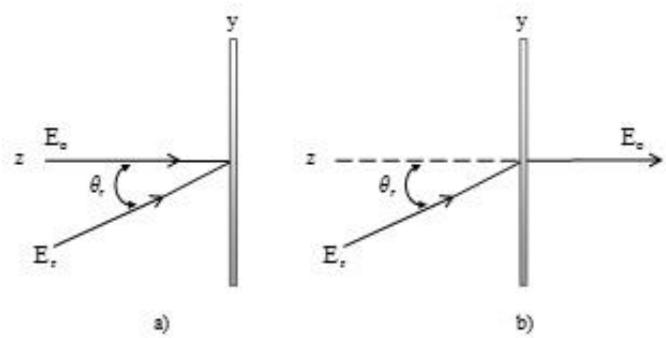

FIGURE 2. a) Formation of a hologram. b) Reconstruction of a hologram.

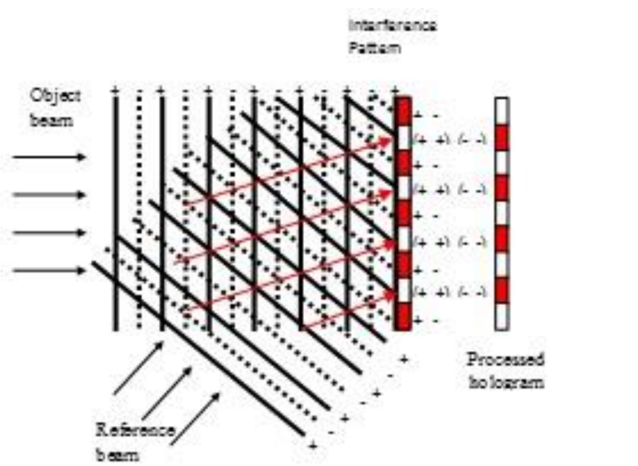

FIGURE 3. Obtained interference fringes when two plane waves interfere and fringe inversion when hologram is processed.

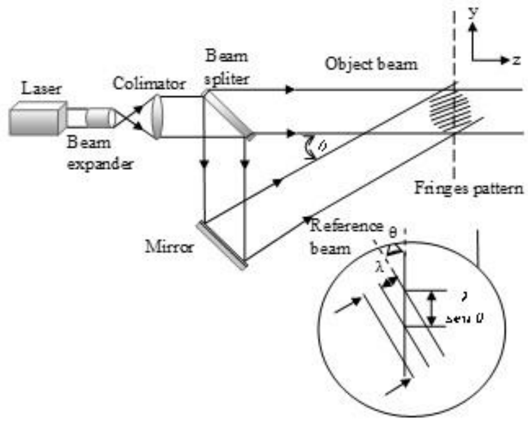

FIGURE 4. Recording of a hologram with two plane waves. If we vary the angle of the reference beam, we can vary the spatial frequency of the recorded fringes.

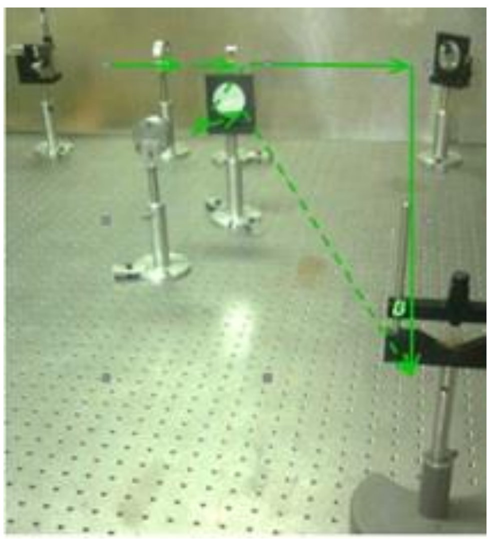

FIGURE 5. Experimental set up for the recording of the multiplexing holograms used in this work.

III. EXPERIMENT

With the purpose of validating our method, we fabricated several multiplexing de-multiplexing holograms according to Equation (1). For that, we used commercial transmission holograms plates, with a very simple optical array, whose picture is shown in Figure 5, and shown schematically in Figure 2.

For hologram fabrication an Ar-ion laser of λ_r=514 nm was used with an angle between beams. For multiplexing purposes, diode lasers of very low cost were used of wavelengths λ_r=405, 535, and 650 nm, that correspond to blue, green and red colors respectively.

Each diode laser was modulated with the aid of audio signals generators, electronic circuits [3] or another kind of sound sources as radio satations or cell phones, etc., in such a way that variations in audio sound intensity were distorted into variations of light intensity.

After that, with the aid of a multiplexing hologram, beams were superposed and sent all together, as a whole beam towards a second multiplexing hologram similar to the first; where each wavelength is separated accordingly, and directed towards photoreceptors, changing now light variations into electrical signal variations. These variations, properly processing with the aid of transducers as loudspeakers etc., are converted into the original sound signals with their respective information. So, sound information is processed with the support of optical signals resources variations. This is shown schematically in Figure 4.

IV. EDUCATIONAL RESEARCH

Many teachers, today want to move past passive learning to active learning, to find better ways of engaging students in the learning process. Investigations of student difficulties with physics are growing in number and in sophistication; researchers gain deeper insight into students understanding of the material taught in and outside classroom. That is why as teachers have to find ways for students to engage in authentic leaning activities and confront students with their own learning (metacognition).

In this work, we present one experimental activity for involve students in technology environment and project work.

Students need opportunities to explore the significance of science in their lives, especially when they use tech every day.

We should encourage the natural curiosity of students and helping them to research using hands on approach and explore topics in depth, not skim many superficially [4].

Before students can really learn new scientific concepts, they often need to re-conceptualize deeply rooted misconceptions, which interfere with the learning. That is why becomes important to explore conceptions and try to change it, but above all students need to be aware of it.

Students has at least two different conceptual models for the nature and behavior of light [5]. It is impossible to construct a coherent model for the treatment of light as a wave, without being able to both to distinguish and to relate certain basic ideas (*e.g.* Wavelength, path length, path length difference and phase difference) [6].

We want to explore if students could identify this concepts in a communication system, and if they could identify wave or particle behavior of light.

A. Instructional context

The educational learning activities was developed looking the students' performance in optics fundamental conceptions.

The primary objective was that students identify the physical phenomena related to geometrical optics and physical optics reviewed in the course, and consider the importance of optical engineering applications.

We work with seventeen engineering students from Figure

6. Multiplexing and de-multiplexing of several wavelengths, using the light reversibility principle with holograms. Each diode laser was modulated with the aid of audio signals generators, electronic circuits [3], or another kind of sound sources –as radio stations or cell phones, etc.–, in such a way that variations in audio sound intensity were distorted into variations of light intensity.

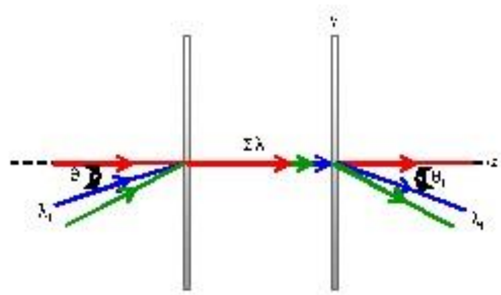

FIGURE 6. Multiplexing and de-multiplexing of several wavelengths, using the light reversibility principle with holograms.

After that with first year with a mean age of 17.8 years, who have been enrolled in a previous course in calculus-based physics (kinematics and dynamics), and basic knowledge about electronics.

For known their conceptions we ask them about light, light ray, particle, reflection, refraction, mirror, lens, diffraction, dispersion, diffraction pattern, image, mirror, hologram, phase, wave length, frequency. Also, they had to research about: communications system function, signal, and transmission, definition and electronic devices uses and function. They form four teams and show each other theirs results; also they received a basic instruction related to build electronic circuits and use of the ammeter.

We present the diagram Block shown in Figure 1, and they had to identify how light travels, and which optical phenomenon and concepts was involved; they had to draw ray paths. The same was with the Figure 3, 5 and 6.

V. RESULTS

The students developed communication skills and assembling electronic circuits and their functions.

They are already familiar with the idea that light from and object travel outward in all directions in straight lines. Reflected light can be refracted and an object is visible because it reflects light. The path of light can be changed, they draw ray diagrams correctly, light could have a wave and a particle behavior, and they have good manage, and they explain in their own words the meaning of fundamental concepts. However, when they have to identify in the system which behavior present the light, they had problems for give any answer.

In Figure 1, they don't have problems to identify phenomenon involved, and calculate the angle in both cases.

In Figure 3 at first, any student drown the right answer, they do not understand how hologram was build and how images could be "store" in plastic thin. They recognize after test and teacher intervention, they know phase definition but they do not really understand how was related with hologram image. They know the relationship between color and wave length, and some of them mention about intensity is related with the number of emitted photon. With this answer they associate different light behavior, they explain also light when come from laser is a particle and light when comes true hologram converts to a wave.

VI. CONCLUSIONS

Making use of the wave nature of light, different kind of information could be send using different wavelengths λ_j, appropriated to perform a multiplexing effect. By making several beams of light, each modulated in amplitude by dissimilar analogical or digital signals, to impinge simultaneously on an holographic grid, which send the beams thorough some kind of waveguide that can be an optical fiber. At the output where information was received, a similar grid was used to separate the different information carriers λ_j, each being addressed towards different corresponding photo detectors for demodulating the desired information.

We fabricated holograms for optical multiplex/demultiplex, using coherent light beams of wavelength $\lambda r = \frac{\sin\theta_r}{\sigma_r}$ nm, where:

Θ_r was the angle between the beams. λ_r is the wavelength of light, and σ_r the spatial frequency of the fringe pattern formed by. For experimentally carry out such purpose, with the aid of holographic plates for transmission the beams.

Modulation of laser light was realized by standard simple electrical circuits which bring out different kind of information for example: audio signals, radio transmitters, cell phones, portative sound reproducers. Also by simple standard circuits for the photo detectors we could convert intensity light variations into electrical signal differences, for each wavelength, which lead to the final information retrieval using corresponding transducers, as loudspeakers, which is the final stage for the information originally sent throughout optical signal variations.

The students were really excited about the experimental work, and they were motivated to build their own holograms and communication systems.

They now recognize how important is known about conceptual and basic science for development technology, and they changed their conceptions about physics.

We identify students had specific misconceptions about light concepts.

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