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Holography: More than three-dimensional images

Augusto Beléndez[1,2], Sergi Gallego[1,2], Andrés Márquez[1,2], Manuel Ortuño[1,2], Jorge Francés[1,2], Jaume Colomina-Martínez[1], Guillem Nájar[1] and Inmaculada Pascual[1,3]

[1]*I.U. Física Aplicada a las Ciencias y las Tecnologías. Universidad de Alicante. Carret. San Vicente del Raspeig s/n. E03690 San Vicente del Raspeig –Alicante. Spain*

[2]*Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal. Universidad de Alicante. Spain*

[3]*Departamento de Óptica, Farmacología y Anatomía. Universidad de Alicante. Spain*

Dedicated in memory of Prof John Sheridan

Holography is a broad field of research that interacts with a wide range of disciplines, from physics and chemistry to art through engineering, as shown by the large number of publications that can be found on the subject. Holography is integrated into our daily lives, often associated with the rainbow-like effect on banknotes, credit cards, and ID cards. Let us also consider that holography involves many optical phenomena (coherence, diffraction, interference, analogue and digital recording devices, lasers, materials, etc.). Therefore, holography is an extraordinarily productive and attractive field as a research area. Furthermore, holographic devices facilitate the development of many applications, some of which are reviewed in the present paper.

Keywords: Holography, Hologram, Holography Applications

> *"Today across the globe holography is a very active area of research. There is simply no way to even briefly outline the breadth of research and engineering activity inspired by Gabor's wonderful invention. Gabor would recognize the dilemma having himself been inspired by his fellow Nobel Laureates Lippmann, the Braggs, Raman (and many others), whose work his own complements. While Gabor foresaw some promising applications, no one could have anticipated how holography would develop and how it could be used to address so many technical problems. We can only wonder at what is yet to come."*
> ***John T Sheridan* (*1964-2022*)**

1 Introduction

The year 2023 marks the 75th anniversary of the publication of Dennis Gabor's paper entitled "A new microscopic principle" [1]. This short article -just over one page- appeared in *Nature* on 15 May 1948 and is the first published article on holography. In those years, Dennis Gabor (1900-1979) [2-6], a Hungarian engineer based in England, was working on improving the quality of the images obtained with the electron microscope, as the systems were imperfect. Its limitation was related to the spherical aberration of the microscopes' magnetic lenses. Gabor wondered how to improve these images and asked himself: "Why not take a bad electronic picture, but one that contains the whole information, and correct it by optical methods?" [7]. The answer to this question occurred to him while he was waiting for a tennis court on an Easter day in 1947 [8] and was to consider a two-step process called registration and reconstruction. Holography had just been born. However, the original idea of Dennis Gabor would have remained a white elephant [9], a

Corresponding author
e mail: a.belendez@ua.es (Augusto Beléndez)

superfluous object without any application, had it not been for the contributions of Yuri Denisyuk (1927-2006) in the former Soviet Union and mainly Emmett Leith (1927-2006) and Juris Upatnieks (1934-) in the United States [3]. It was only with the invention of the laser –one of the most important and versatile scientific instruments of all time– in 1960 and its commercialisation in 1962 that holography proved to be a very productive and attractive field of research. Gabor was awarded the Nobel Prize in Physics in 1971 “for his invention and development of the holographic method”.

Over the last seventy-five years, the many applications of holography in many different scientific and technical areas have given rise to “hot topics” [10-12]. The basic principles involved in hologram recording and reconstruction continue to give rise to exciting innovations in a wide range of areas: three-dimensional imaging, holographic interferometry, pattern recognition, image processing, holographic portraits, communications, optical elements, head-up displays, acoustic holography, particle detection, optical storage, solar energy conversion, optical encoding, digital holography, security, packaging, sensing, etc.

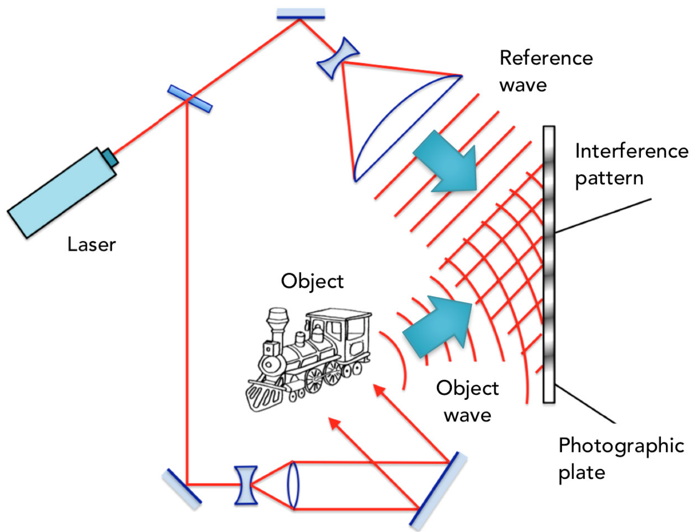
2 What is a hologram?

Photography is the traditional way of producing and storing permanent images of objects that emit or diffuse light. The first photographic images in history were made two centuries ago by Joseph-Nicéphore Niépce (1765-1833), although Louis Daguerre (1787-1851) perfected Niépce’s method from 1839 onwards. It is well known that the three-dimensional character of the photographed object is lost in a photograph because what we see on paper or on a computer screen is a two-dimensional version of a three-dimensional object. However, as mentioned above, Gabor’s research initiated in 1947 led to the birth of a technique for storing images in three dimensions, holography, whose development and applications continue today.

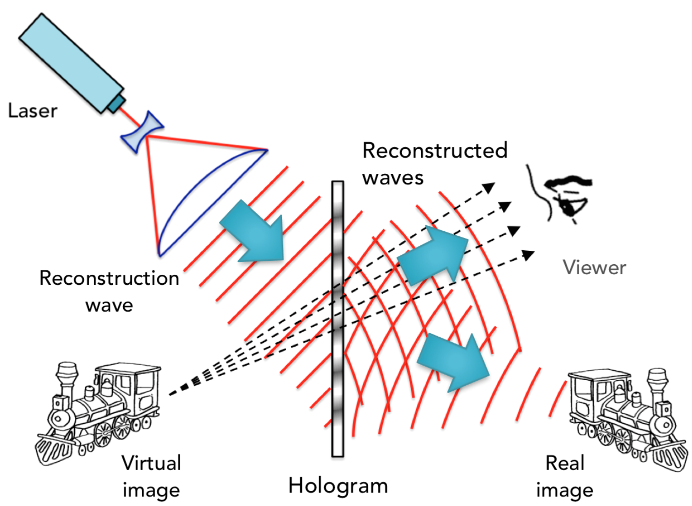
But, what is a hologram? To a physicist a hologram is the recording of the interaction of two coherent waves in the form of a microscopic pattern of interference fringes on a suitable photosensitive medium. To a layman, but well-informed physicist, it is a photographic film or plate of other photosensitive material that has been exposed to laser light and processed in such a way that when conveniently illuminated it produces a three-dimensional image [13]. For someone who is less informed, holography is a kind of three-dimensional photography. However, photography and holography produce the image in a completely different way, and it is not possible to describe in the same terms how the two types of images, photographic and holographic, are formed. It is easy to show how the objective lens of a camera forms the image of an object on the CCD sensor by simply using ray tracing and basic concepts of geometrical optics. To record this image, photographic cameras initially used photosensitive emulsions, although digital CCD sensors have been used for some years now.

Because the photographic technique has been known for so long, we are used to seeing the three-dimensional world compressed into the two-dimensionality of a photo album page, a magazine or the cinema or television screen. They all share the limitation of being only representations of the intensity of light waves. In other words, when the image of a scene is reproduced photographically, what is finally observed is not a precise reproduction of the light wave that flooded the object, characterised by its amplitude and phase, but rather a point-by-point recording of the square of the amplitude of this wave. The light reflected in a photograph carries with it information about the amplitude, but nothing about the phase of the wave that came from the original object. However, if both the amplitude and phase of the original wave could somehow be reconstructed, the resulting wave would be indistinguishable from the original. This is easy to understand if we consider that when we look at an object, what comes to our eyes is the wave emitted or diffused by the object. Therefore, if we somehow managed to reproduce that wave, and it reached our eyes, it would appear to us as coming from the original object. We would then be able to see the image formed in perfect three-dimensionality, exactly as if the object were actually in front of us.

This is what can be achieved by holography, a method of obtaining three-dimensional images, which consists of two stages called recording and reconstruction. The registration process stores the information in certain photosensitive materials, in the form of an interference pattern, in order to later reconstruct a wavefront almost identical to the one that gave rise to that information. The impressed and processed photosensitive material, the carrier of this information, constitutes the hologram, from the Greek "holos" meaning totality. A fundamental difference with photography is that now, instead of storing the two-dimensional image of the object, sufficient information is stored to be able to reproduce the object wave itself. It is as if with holography it is possible to "freeze" the wave from the object and then "set it in motion again". In this sense a hologram is like a "window with memory" [14].



(a)



(b)

Fig 1. (a) Recording and (b) reconstruction of a transmission off-axis hologram from a diffusing object (Leith and Upatnieks' hologram). Looking through the hologram we can see a virtual image of the three-dimensional object, giving a sense of relief. Credits: A Beléndez.

The production of a hologram requires the recording and reconstruction of light waves and a hologram is said to contain the encoded recording of an object wave. To explain the formation of the holographic image it is necessary to resort to the concepts of interference and diffraction, both of which are characteristic of wave phenomena. In the recording stage, the wave emitted or diffused by an object is interfered with a known reference wave (Fig 1). The "holographic code" consists of "mixing" the object wave with the reference wave and recording its interferential pattern on a photosensitive material such as photographic film, resulting in the hologram [11]. The hologram contains encoded information on both the amplitude and phase of the object wave. To decode the information stored in the hologram and thus reconstruct a replica of the original object wave, in the reconstruction stage the hologram is illuminated with a wave analogous to the reference wave used in the recording stage. This wave is diffracted by the complex fringe structure stored in the hologram, generating an image wave with similar characteristics to the original object wave. Thus, if you look through the hologram, you will see a three-dimensional image of the object, even if it is no longer there, because its wave is available and it is this that reaches your eyes. This reconstructed image wavefront is virtually indistinguishable from the original wave from the object and can produce all the visual effects of the primitive beam.

For interference to occur, the light must be coherent like a laser. In the simplest hologram (Fig 2), both the object and reference waves are plane waves. If the angle between the directions of propagation of the two plane waves is 40º, and the light comes from a He-Ne laser whose wavelength is 633 nm, the distance stored between the interference fringes is 0.001 mm. This means that there are a thousand fringes for every millimetre of the hologram's surface. To successfully store this number of fringes per millimetre, the photosensitive material must have a high enough resolution. Furthermore, it is essential to ensure that the experimental system is not subjected to any vibration during hologram recording. All these requirements have conditioned the advancement of holography in two areas. On the one hand the provision of sufficiently coherent light sources and on the other the development of new recording materials to produce holograms. [15]. The development of the laser from 1960 onwards solved the first of these difficulties while using different photosensitive materials suitable for hologram recording overcame the second. As a result, holography and its countless applications have been developed.

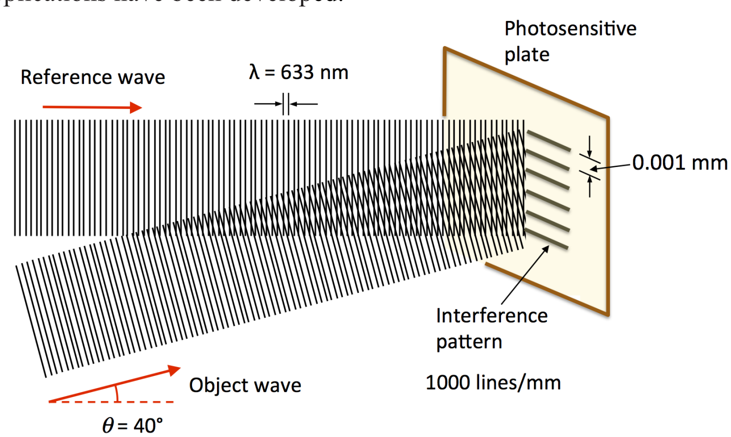
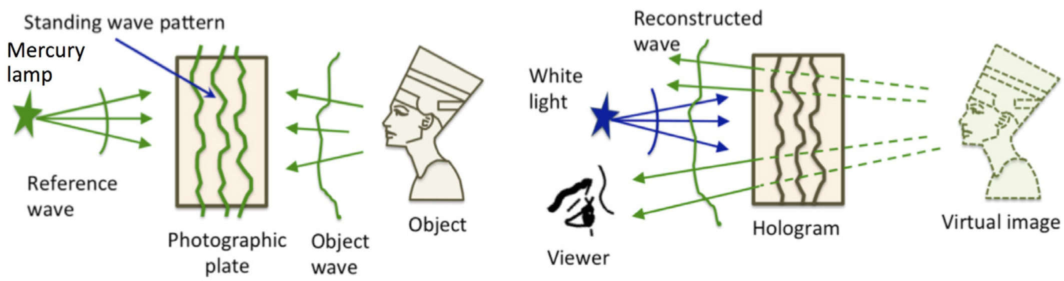


Fig 2. Transmission holographic recording stage using a He-Ne laser. Credits: A Beléndez.

The hologram shown in Fig 1 is called a transmission hologram. Its distinguishing feature is that the reference and object beams are located on the same side of the photosensitive material plate. To record and reconstruct this type of hologram, laser light must be used, which forms a real and a virtual image at the site of the original object. The object can be seen in three dimensions by looking through the hologram. Another type of hologram is the reflection hologram (Fig 3), which was first developed by Yuri Denisyuk in 1962 [3].



(a) (b)

Fig 3. (a) Recording and (b) reconstruction of a reflection hologram (Denisyuk's hologram) using a mercury lamp and white light, respectively. Credits: A Beléndez.

In this case, the object and reference beams are each incident on one side of the photosensitive plate. After passing through the plate, the light wave is reflected by the object and interferes with the incident wave, giving rise to a standing wave pattern that can be recorded on the photographic plate. This plate, once developed, is illuminated with white light, and the object appears in its original position and in the colour of the light used in the recording. This type of hologram, the reflection hologram, played a significant role in the future evolution of holography, and it is the technique commonly used for recording holograms of three-dimensional objects (Fig 4).

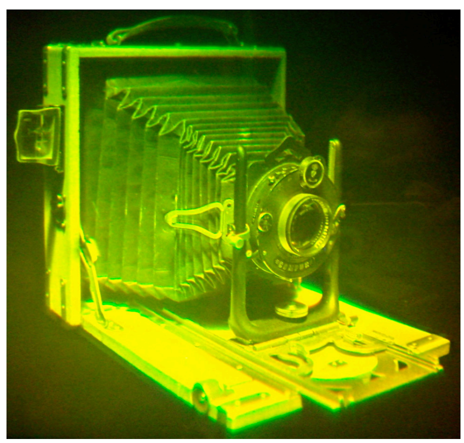


Fig 4. Reflection hologram of an ancient camera. Deutsches Museum (Munich). Credits: A Beléndez.

3 What can be achieved with holography?

Although reconstructing a three-dimensional image, which appears to be in perfect relief, is undoubtedly one of the most spectacular and well-known achievements of holography, many other applications exist in very diverse fields. One of the first scientific and technological applications of holography was holographic interferometry, a compelling non-destructive analysis method. This technique was discovered accidentally by Kart Stetson and Robert Powell in December 1964 [16], although Leith and Upatnieks had already realised the possibilities of holography in interferometry at the end of 1963. Using this technique, it was possible to visualize the vibratory modes of musical instruments, study the deformation of objects under tension or analyze the temperature distribution, for example that which occurs inside a light bulb. Along the lines that appear on the interferogram of the image, the temperature was constant. This technique may be applied to study transport phenomena, visualise fluid flow, measure components in hostile or corrosive environments and perform non-destructive testing. It may even be applied in other fields, such as orthopaedics, to study bone deformations and prostheses or in studies concerning the conservation and restoration of works of art. Figure 5 shows a real-time holographic interferometric study of the temperature distribution inside a light bulb. Along the lines shown in the interferogram, the temperature is constant.

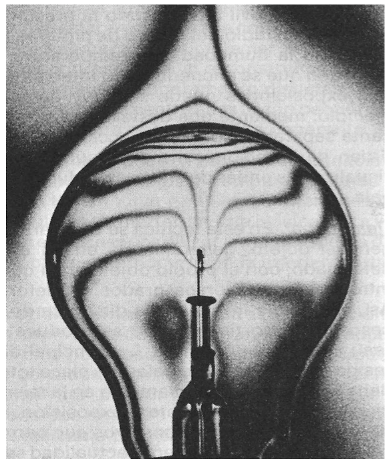


Fig 5. Study by means of holographic interferometry of the temperature distribution inside a light bulb. Credits: University of Alicante (1984).

Analysis of microscopic particles distributed in a specific volume is another field in which holography has proven very useful [17]. In this case, both on-axis and off-axis configurations may be used, and a pulse laser is usually employed. This technique allows us to analyze the size, position, displacement and speed of the particles [18] and allows us to study everything from aerosols to systems such as marine plankton. It has even been used to analyse the dynamics of microscopic particles and growth of crystals in conditions of microgravity in experiments carried out on board the Space Shuttle Discovery in the mid-1990s [19], in which over a thousand holograms were recorded, thereby providing a true "virtual" space laboratory on Earth.

Holographic techniques are used to manufacture holographic optical elements (HOE) such as diffraction gratings, mirrors and other more complex devices [20] such as optical fibre interconnectors [21] or solar concentrators [22,23] using holographic mirrors or lenses (Fig 6). Then there are holographic scanners [24] used to read bar codes, which consist of a disk divided into sectors, each of which is a holographic lens that deflects the incident light in a specific direction (Fig 7).

HOEs can also be found in holographic displays, known as head-up displays (HUD) [25]. In these systems, the HOEs allow the observer to see an image with an infinite amount of information displayed on a screen and superimpose it on the outside scene. HUDs have been incorporated in fighter-pilot helmets and inside aircrafts. This technology has crossed the border from military to civilian applications, and HUDs can be found in other types of aircraft and even in some cars. In the latter case, these devices – known as automotive head-up displays [26] – allow the driver to see information such as the speed of the vehicle on the windshield without having to take their eyes off the road.

HOE can also be found in optical information processing devices, laser beam focusers in CDs and DVD player heads, and systems to correct aberrations of conventional lenses such as those in telescopes, laser protective glasses, etc. [20].

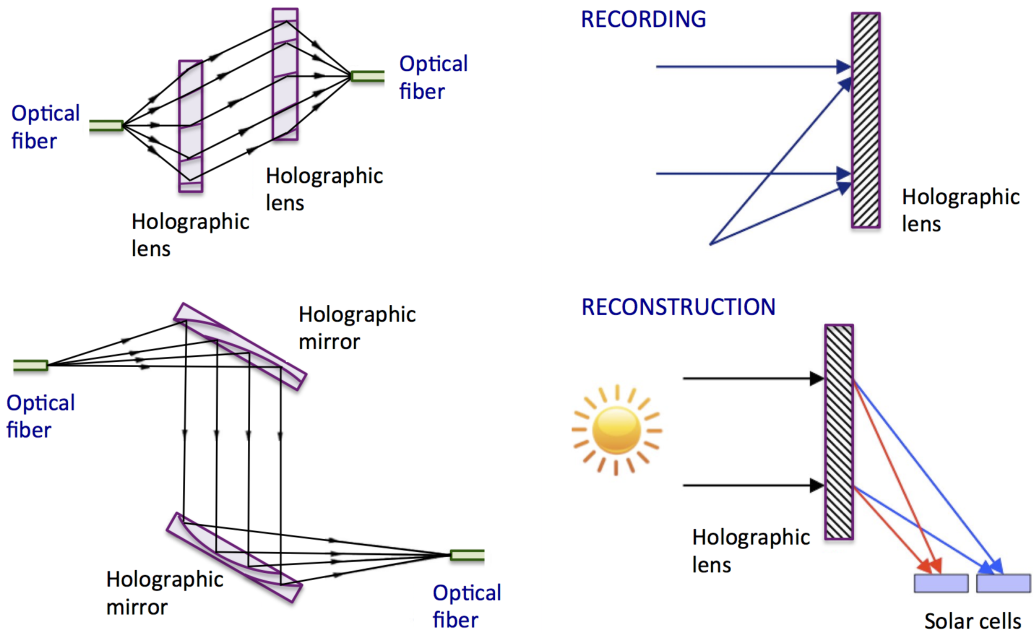


Fig 6. HOEs used as fibre optic interconnectors using both holographic lenses and mirrors (left) and solar concentrators (right). Credits: A Beléndez.

Another vital application of HOEs is in the field of astronomy. For example, Volume Phase Holographic Gratings (VPHGs) are dispersing elements widely used in astronomical spectrographs. They are considered the baseline for future instruments thanks to their high efficiency and easy efficiency customisation [27].

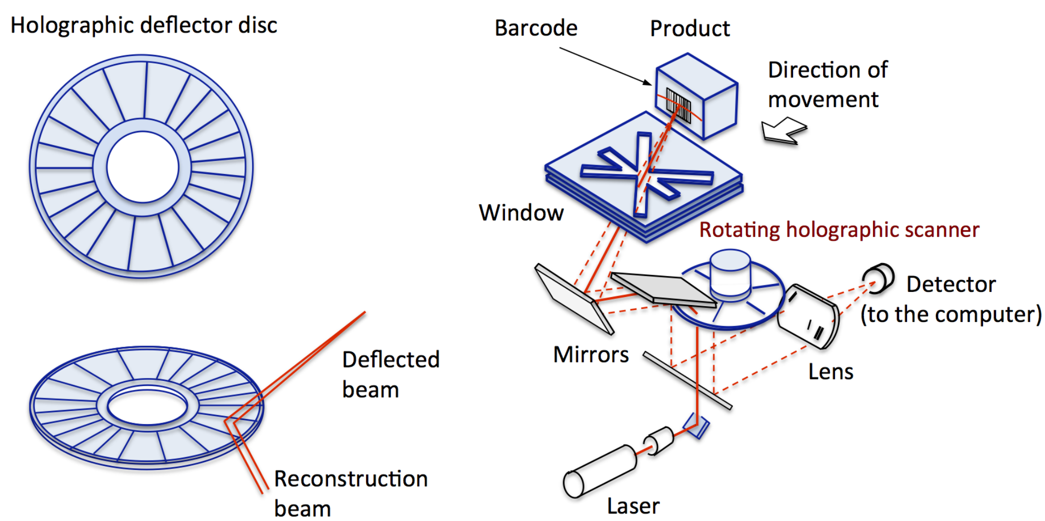


Fig 7. HOE used in the 1990s as scanner for barcode reading. Credits: A Beléndez.

Currently, technologies related to augmented reality, 3D imaging, mixed reality and see-through applications are proving to have great potential as well as being very attractive. For example, augmented reality allows users to observe computer-generated virtual perceptions in real-world environments, and HOEs can provide exciting solutions for injecting and extracting images into waveguides that are part of see-through devices [28].

The possibilities that offer HOEs for photovoltaic and see-through display applications open new possibilities for holographic recording materials. In this sense, some specific characteristics are required for each particular application. Waveguides are one of the key elements for these applications, and photopolymers are one of the most competitive candidates for waveguide fabrication [29,30].

Neutron optics experiments and neutron spectroscopy are critical techniques for condensed matter physics as well as fundamental physics, and HOEs have been fabricated for use with neutron beams [31,32]. HOEs can also be applied to multiplex and de-multiplex signals, implement permutations and perform shuffling. In addition, the use of Spatial Light Modulators (SLMs) and Micro-Electro-Mechanical Systems (MEMs) has opened the door to programmable illumination in imaging systems, adaptive neural networks that learn and can be trained [33].

Computer-generated holograms (CGH) can also be produced, in which the interference pattern is calculated with a computer and projected onto the surface of the hologram using, for example, an SLM. The possibility of producing smaller pixels has increased the quality and possibilities of these holograms. CGHs allow the possibilities of classical holography to be generalised and were first produced in 1966 by Lohmann and Paris [34]. Adolf Lohmann, one of the first who had become interested in Gabor's technique in the 1950s, had been working since the early 1960s in the Optical Signal Processing Department of IBM in San Jose, California (USA), and was the only member of the team who had a deep knowledge of optics, both theoretical and experimental, as well as of computer programming [2]. It is important to note that in a CGH, it is not necessary for the object, from which the hologram is made, to have a real existence. Any object can be defined by giving the coordinates and intensities of its points, and the hologram obtained allows the object to be visualized in three dimensions. It is possible to create geometric figures in space or to represent objects in the process of being manufactured without having to build models. These holograms also provide original solutions for optical filtering procedures, information storage and, in general, optical information processing. Further, these holograms are just one part of a broader field known as digital holography [35].

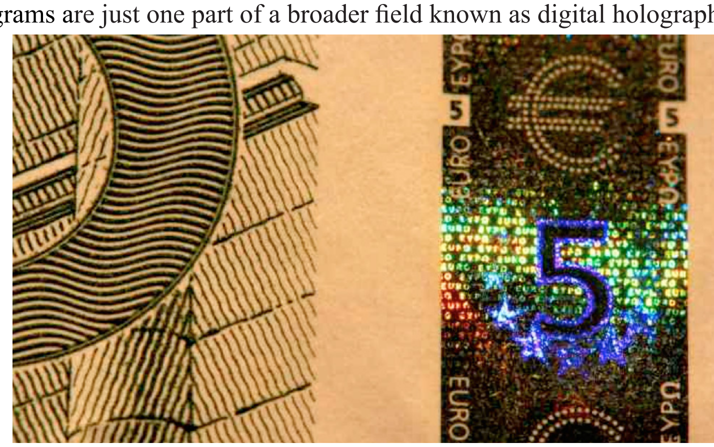


Fig 8. Hologram on a 5-euro banknote. Credits: Wikipedia.

In our society, dominated by information technologies, using holography to store information is currently one of its most exciting applications [36]. Multiplexing allows a large number of holograms to be recorded on the same plate, and the individual holograms are subsequently recovered [37]. This is the principle of holographic memories in which a great amount of information may be stored in a small space. However, the greatest technical difficulties in implementing this technique concerned finding suitable recording material.

Security hologram [38] is the most commercially significant application of holography (Fig 8).

The technical difficulty of making holograms and the fact that only complex and sophisticated means can mass-produce copies of an original hologram have made holography suitable for security systems such as those used for credit cards, banknotes, identity cards or labels on commercial products, including some pharmaceutical products marketed in Southeast Asia, where the sale of illegal medicines is widespread [39]. In all these cases, the use of holograms is intended to prevent or at least make it much more challenging to counterfeit [40]. Holographic methods are also starting to be used for fingerprint authentication [41].

In 2014, a paper was published in Advanced Optical Materials [42] that demonstrated the possibility of using holographic sensors based on the properties of reflection holograms, in particular Bragg's law, since when illuminated with white light, the colour of the reflected light depends on variations in the thickness of the hologram as the separation between the stored interference fringes changes. This type of sensor has been proposed for applications such as pH measurement and even medical diagnostics. Nowadays, the development of holographic biosensors for biomedical applications is an emerging application in the field of holography [43]. Recent studies show the possibility of using holographic gratings as sensors with high sensitivity, easy manufacturing, low cost, disposable, and easy to market [4].

The principle of holography is also applied to longitudinal waves, such as acoustic waves, giving rise to acoustic holography [45]. In this case, two sound waves are interfered with to realise the acoustic hologram, while laser light is used to illuminate this hologram and obtain a recognisable image.

It is also possible to obtain holographic portraits. The first was taken on Halloween night, 1967, and was a self-portrait of Lawrence Siebert [46] of the Conductron Company in Ann Arbor, Michigan (USA). Making holograms of people presents two significant problems. Firstly, people should be completely still during the exposure. Secondly, people tend to close their eyes when exposed to the laser light. Even if the person tries to be completely still, they cannot stop breathing, their muscles are not stiff, and their heart is still beating. Breathing, muscle movement and heartbeat give rise to movements that prevent the creation of a hologram with continuous lasers, Siebert solved this problem using pulsed lasers whose short light pulses last only a few nanoseconds. By using such lasers, holographic portraits are possible, as the alteration of the scene to be recorded is practically nil for the duration of the pulse. A historical holographic portrait is the transmission hologram of Dennis Gabor, made in 1971 to celebrate the awarding of the Nobel Prize in Physics [47].

Museums have used holography to substitute particular valuable, delicate objects with holograms [48]. This was the case of *Lindow Man*, Iron Age man, a mummy over 2,300 years old found in Cheshire (England) in 1984. The *Lindow Man* hologram is a white light reflection hologram made by Richmond Holographic Studios Ltd. in 1987. The original is kept at constant temperature and humidity in a vault in the British Museum in London. In contrast, a hologram of the mummy was made and exhibited so that it could be seen by the general public and studied by various researchers. Making holograms of valuable pieces allows the latter to be viewed in places other than where they are actually kept. Denisyuk-type holograms were used in the former Soviet Union and other countries within the framework of a vast programme of collaboration between physicists and museologists to conserve works of art considered archaeological treasures. The Denisyuk technique often substitutes the original objects with holograms in travelling exhibitions. In 1984, a series of holograms reflecting the *Tesoro de Villena* (Fig 9) were recorded at the University of Alicante, and holograms of this type have been used in several countries for the conservation of works of art considered archaeological treasures through a vast programme of collaboration between physicists and museologists.

The problem with transmission holograms recorded with the light of a single laser is that when reconstructed, they appear in that colour. The same happens for reflection holograms when they are recorded using a single laser. When reconstructing the holograms with white light, the image appears in the colour of the laser light used during the recording stage. However, colour holograms can be obtained by using three

Fig 9. Reflection holograms of the Treasure of Villena made by J A Quintana at the University of Alicante (Spain) in 1984. Credits: A Beléndez.

lasers with wavelengths in the areas of the three primary colours (Fig 10) [49], Denisyuk's technique allows the recording and reconstruction of colour images with an unthinkable quality. The fidelity in the reproduction of shapes, colours and brightness is so spectacular that it is difficult to tell whether what one sees is the object itself behind a glass window or a holographic reproduction [50].

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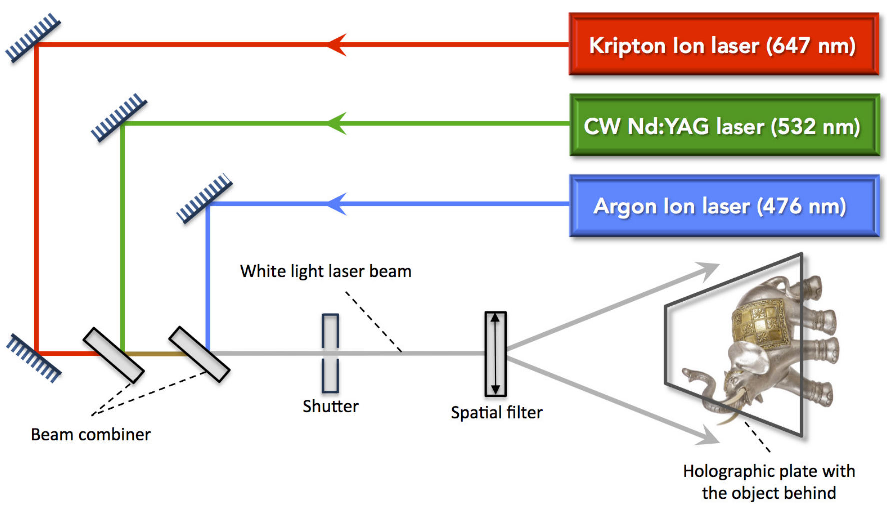

Fig 10. Recording of a colour reflection hologram using three lasers [50]. Credits: A Beléndez.

Recording material plays a critical role in enabling the development of new applications of holography. Fully understanding and characterizing holographic recording materials as well as the optoelectronic systems and devices used in holography provides improvements in both the development and commercialization of modern technology related to holography [5]. It is clear, therefore, that the recording medium plays an essential role in holography, and numerous recording materials have been tested, used and evaluated as recording media for the manufacturing of different types of holograms. A large body of literature describes holographic recording materials and their development according to the wide variety of applications in which the materials are to be used [15,51,52]. These recording materials include photographic emulsions, photoresists, dichromate gelatin, photochromics, photorefractive crystals, thermoplastics, photorefractive and thermoplastic crystals, photopolymers, etc. However, in many holographic applications, photopolymers are preferred because of being self-development along with a high resolution [53]. Photopolymers have proven to be useful for different holographic applications such as holographic data storage, HOEs or holographic sensors [43,54,55], and some commercial photopolymers such as Bayfol® HX films (Covestro AG, Leverkusen, Germany) [56] are being used with great success in numerous holographic applications.

4 Holography: art with light

"It's the intersection of art, science, and technology that makes holography so interesting", [57] stated Stephen Benton (1941-2003), a key figure in the development of modern holography not only on account of his scientific achievements (such as the holograms on credit cards) but also for his artistic talent. In addition to countless scientific and technological applications, holography is one of the few scientific fields that have provided a medium for art. Stephen Benton first saw a hologram in 1964 and since then he always said that it was the most fantastic thing he had ever seen in his life.

In 1966 Leith and Upatnieks made a hologram in collaboration with the photographer and artist Fritz Goro (1901-1968) for the journal Life, and in 1968 the article "Holography: A New Scientific Technique of Possible Use to Artists" [58] was published in the journal *Leonardo*. This article discussed the possibility of using holography as a new art form, and several artists began to experiment in this field. One of the most important was the artist Margaret Benyon (1940-2016) [59], who made her first hologram in 1968. Also in that year, the first exhibition of artistic holography was held in Michigan –the world centre of holography at that time– and the second in New York in 1970. In 1971 a school of holography opened in San Francisco, where scientists, engineers and artists could learn this new technique. Holography thus became an unusual example of a scientific field whose development involved groups of people from very different backgrounds. Anybody who has seen a hologram will agree that holography is one of the most interesting revolutionary techniques for creating three-dimensional images and its capacity to fascinate is unquestionable. As opposed to the static, constant nature of paintings or photography, holography implies movement of the observer and variation of the image since different angles of vision are produced during the dynamic perception of a holographic image (Fig 11).

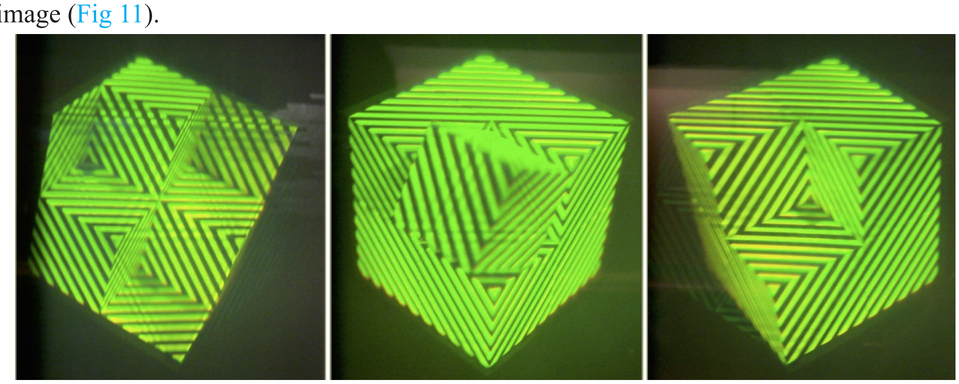

Fig 11. Views from different angles of the image reconstructed by a hologram, showing changes in perspective. The hologram is on display at the Deutsches Museum (Munich). Credits: A Beléndez.

Salvador Dalí (1904-1989), surrealist artist and eccentric genius, also dabbled into holography as a medium for his art. Between 1971 and 1976 Salvador Dalí and the South-African artist Selwyn Lyssack [60] collaborated to produce seven holograms. The artists received technical assistance from Conductron Engineers to produce holograms with pulsed laser and the Multiplex Company to make holographic stereograms [2]. Dalí exhibited his holograms in the Knoedler Gallery in New York in 1972 and 1973 and Gabor himself attended [2]. One of the holograms made in 1973 was entitled “Brain of Alice Cooper” and was a holographic stereogram of Alice Cooper, hard rock and heavy metal singer, a true rock icon, born in 1948 [2]. Another of the holograms conceived by Dalí in 1975 entitled “Melting clock” was not actually made up until 2003 when Selwyn Lyssack did so from Dalí’s original sketch. Both Dalí’s sketch and the hologram were auctioned in 2014 at Sotheby’s. The auction estimate for the lot was between 100,000 and 150,000 US dollars. In fact it was sold for 269,000 US dollars.

The Swedish painter and sculptor Carl Fredrik Reuterswärd (1934-) is another established artist who entered the world of lasers and holography [61]. He began to study the possibilities of holography as an art form in 1969 and received technical assistance from scientists at the University of Uppsala, Sweden, and the Royal Institute of Technology (RIT) in Stockholm, Sweden, such as Hans Bjelkhagen [62]. Like Dalí, Reuterswärd also made several truly unique holograms. "Kilroy" was the main work of this artist, which is composed of several individual holograms titled “The Hand”, “The Seal”, “The Dog's Bone” or “The Heart”. Another example is a reflection hologram entitled “Cross Reference” in which Reuterswärd poses as none other than Dalí himself.

Between 2004 and 2005, the Japanese artist Hiro Yamagata exhibited his work entitled “Quantum Field-X3” outside the Guggenheim Museum in Bilbao (Spain) [63]. It consisted of two huge structures covered with holographic panels, onto which laser beams were projected to create a vibrant composition. Visitors entering the structures were given a stunning experience of light and colour that their unaided senses would find almost impossible to perceive. Overcoming the natural limits of human perception, the hologram made light beams give rise to a fascinating play of light and shapes.

In summary, holography is of undeniable interest as one of the most revolutionary techniques for creating three-dimensional images, and its enormous capacity for attraction-fascination. Holographic space involves the movement of the viewer, which gives rise to a variation in the image that the viewer perceives, since different viewing angles occur in the dynamic perception of the holographic image.

5 Conclusions

Although the reconstruction of a three-dimensional image giving the sensation of relief is undoubtedly one of the most spectacular and well-known achievements of holography, there are many other applications in very different fields. The manufacturing of security holograms has become a big business. This type of holograms can be found on credit cards, bank notes, and there are even holograms on the labels of certain products, such as sports clothing. All this is to guarantee the authenticity of the products and distinguish them from imitations. Holographic interferometry is a technique applied in many different areas. Holographic optical elements are used in a wide variety of optical systems, and holography is also used for optical information storage and the manufacturing of sensors. Holography has given rise to many applications and has provided techniques that can be used in almost any area of pure or applied research. It is, therefore, difficult to find a scientific or technical field in which holographic methods cannot be applied and it is difficult to find a research activity in which holographic techniques are not used for some of its developments, including such seemingly distant areas as archaeology or palaeontology. Finally, it should be noted that holography could be applied using a large part of the electromagnetic spectrum, from microwave and radar imaging, through infrared, visible spectrum and ultraviolet radiation, to X-rays. Electron or neutron beams and even sound waves can also be used to record holograms.

There is no better way to end this brief overview of some applications of holography, in memory of our colleague and friend John (Séan) T Sheridan, than with some words of the holographic pioneer Emmett Leith, who in 1986 stated [64]: *"Holography by itself is somewhat narrow field, but combine it with others and it makes an area big enough to spend a lifetime in."*

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