European Journal of Physics

One-step real-image reflection holograms

INSTITUTE OF PHYSICS PUBLISHING EUROPEAN JOURNAL OF PHYSICS

Eur. J. Phys. **28** (2007) 359–365 doi:10.1088/0143-0807/28/2/021

One-step real-image reflection holograms

Paul K Buah-Bassuah[1], Maurizio Vannoni and Giuseppe Molesini

CNR—Istituto Nazionale di Ottica Applicata, Largo E Fermi 6, 50125 Firenze, Italy

Received 12 January 2007, in final form 24 January 2007
Published 21 February 2007
Online at stacks.iop.org/EJP/28/359

Abstract

A holographic process is presented where the object is made of the real image produced by a two-mirror system. Single-step reflection hologram recording is achieved. Details of the process are given, optics concepts are outlined and demonstrative results are presented.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Holography is a fascinating branch of physical optics where basic concepts and processes, such as coherence of light, interference, diffraction, polarization and imaging, all play a role in recording and reconstructing light propagation phenomena [1, 2]. It also offers the opportunity of thinking about the mechanism of 3D visual perception, and about the object itself of vision, that is pure light.

Manipulating light and images can also be performed classically with lenses and mirrors, with still striking effects such as the appearance of immaterial objects. The latter effect is obtained, for example, with optical systems made of two concave mirrors placed on top of one another; the upper mirror has an opening at the centre for light to go through, while the object to be displayed stands at the centre of the lower mirror. A real image is formed directly above the opening, similar to the true object but deceivingly immaterial [3].

Producing real images by holography is generally made with a two-step process. First a virtual image is recorded, and then after it, playing back the object holographically, the real one is produced and recorded. In this paper, we present a process where instead mirror imaging is used to relay the object, so that there is no need for the first step recording. Real-image reflection holograms are produced in a single step by a simple set-up and viewed directly in white light thanks to the properties of this hologram type. Details of the optical set-up, materials and processes are provided, and concepts of physical and geometrical optics are

[1] On leave from Physics Department, University of Cape Coast, Cape Coast, Ghana.

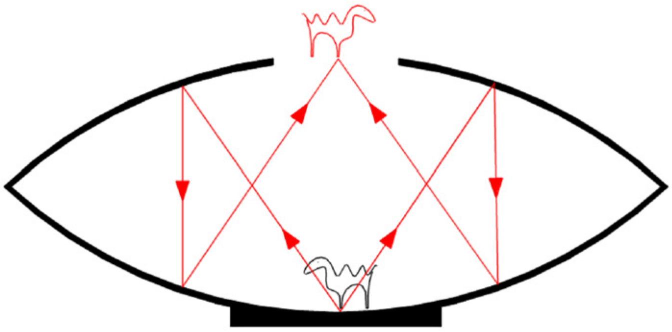

Figure 1. Schematic layout of the two-mirror system.

outlined. Results of a demonstrative experiment are also presented. The educational content is adequate for an advanced laboratory course of applied physics at undergraduate level and offers elements of interdisciplinary learning with chemistry and photography.

2. Real images with a two-mirror system

The distinction between real and virtual images is relevant both to optics equations [4] and to light propagation phenomena. As is well known, real images are such that light truly emanates from them, as occurs with real objects. Conversely, virtual images only appear to originate from objects, but no such light-emanating objects exist at the location where we see them. Real images are ordinarily produced by lenses and mirrors, as well as virtual ones; to see them visually, however, an eyepiece is generally used in optical instruments, to aid the eye in collecting light from all the field of view. Wide aperture and viewing angle optical systems are also possible, where the image can be observed without the need for an eyepiece. This is the case for the pair of equal concave mirrors schematically shown in figure 1.

Such parabolically shaped mirrors are mounted in confocal position, so that the bottom object is at the focus of the upper mirror. At reflection, light is collimated and directed to the lower mirror. In turn, the lower mirror reflects the light upward so that a real image is produced at the opening of the upper mirror. Since the object is placed on a reflective surface (the lower mirror), a further image just below the object is usually visible, both directly and below the opening. This extra image can be avoided, for example, by placing a disc of black cardboard below the object, as we did. The effectiveness of the presentation is outstanding, with the real image appearing to hover at the top of the ‘flying saucer’ structure; any attempt to touch it with fingers is defeated. Systems of this kind are now found in most optics shops and science stores. In figure 2, we show one such system at work, using a pencil sharpener as the object. From where the photograph is taken, both the real image (upper) and the true object (lower) are visible. At lower elevation angles, only the real image is visible, so that the illusion of a material object is not contradicted and the visual effect is fully achieved.

The use of a two-mirror system as above was proposed as a means to teach geometrical optics [5]. Here, we briefly discuss the optical layout in terms of the issues that are relevant to applications in holographic recording. As is customary in optical engineering, for the purpose of analysis, reflections are unfolded, and concave mirrors are represented as transmissive converging elements similar to positive lenses. With the usual notation of double arrow lines, the first-order layout of the system is outlined in figure 3. This figure is drawn to scale,

Figure 2. Two-mirror imaging of a simple object (pencil sharpener). The image is at the top and the object at the bottom.

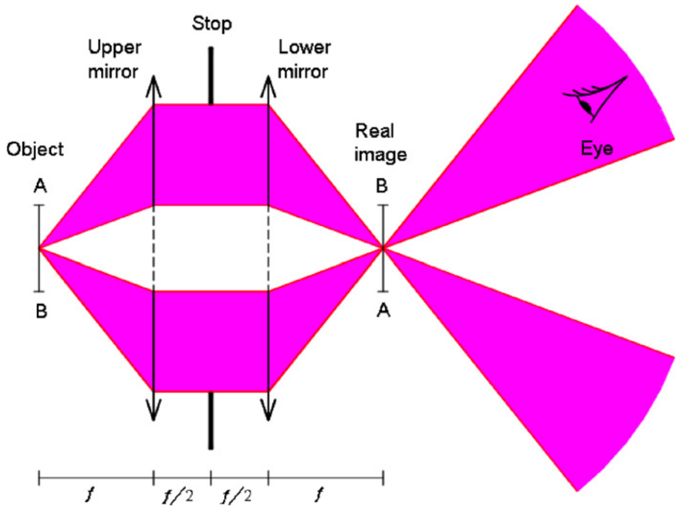

Figure 3. Unfolded layout of the two-mirror system showing the light bundles for a central object point source.

referring to a typical two-mirror system with focal length $f \approx 80$ mm. Due to symmetry about the stop, the lateral magnification of the system is unity (although the image is reversed upside down with respect to the object). Being the square of the lateral one, the axial magnification is therefore also unity, so that an almost undeformed 3D real image is produced. The eye of

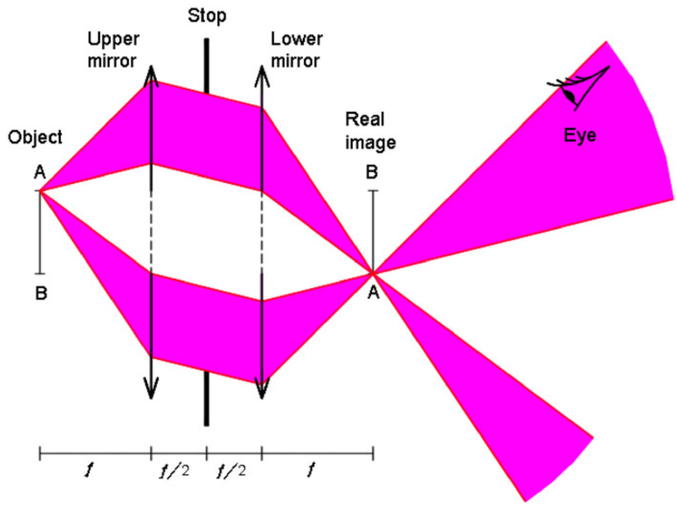

Figure 4. Unfolded layout of the two-mirror system with the light bundles for an edge object point source.

the observer is placed off axis, at some distance from the system, and receives light from the central point source of the object. If we consider a point source about the edge, as shown in figure 4, light is somewhat offsided but is still reaching the eye thanks to the extremely wide aperture of the light beam. The observer then perceives the whole image and automatically locates it in space as with true objects.

3. Holographic set-up

While reflective optics have already been used for holographic work [6, 7], to the best of our knowledge no reflection hologram made with two-mirror systems as above has actually been reported so far. Reflection holograms were introduced in 1962 [8]; since then, the development of high-resolution holographic material gave full effectiveness and extraordinary perfection to images so recorded. As a peculiarity, while transmission holograms require for reconstruction a narrow band source or a laser (unless special techniques such as those for rainbow holograms are used), reflection holograms perform naturally as monochromators by virtue of selective phenomena within the emulsion layer of the holographic material, so that reconstruction can be achieved directly in white light [9].

We use the optical set-up outlined in figure 5. The light source is a 2 mW random-polarized He–Ne laser at the wavelength $\lambda = 632.8$ nm. With the help of a 25×, 0.45 NA microscope objective the beam is made to converge and then to slowly diverge; a pinhole at the focus of the objective provides spatial filtering, so that a clean bright light spot of several centimetres in diameter is available at a distance of $\sim$1 m. A bridge mounting with a 45° plane mirror bends the beam down to the two-mirror system and to the object inside, so that the real image is formed at the opening. Not indicated in the figure, a removable beam blocker (a card for example) is arranged to act as a manual shutter.

The holographic plate is placed on top of the two-mirror system, resting on the opening. The plate then receives direct light from above and light that, after passing through the plate and illuminating the object, makes up the real image from below. Conditions for the formation

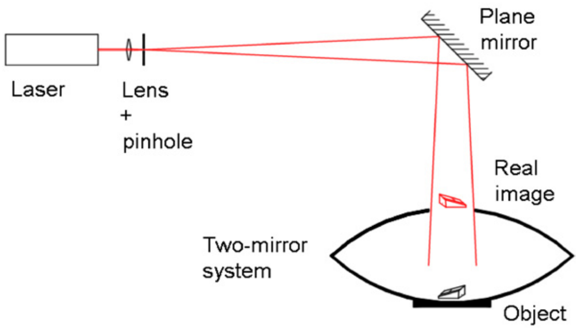

Figure 5. Schematic of the optical set-up to record one-step real-image reflection holograms.

of a reflection holographic grating are then met, provided that a suitable coherence length of the source is available. In fact, the laser type we use is known to have a coherence length function with a periodic structure[2]. As it can be verified for example with a Michelson interferometer by varying the length of one arm [10], the optical path difference where interference fringes are periodically disappearing is approximately 20 cm. In our case, since the optical path difference is $4f \approx 32$ cm, coherence conditions for hologram recording are secured.

A peculiar feature of the configuration adopted is that the holographic plate also acts as a beam splitter; the splitting ratio is, however, fixed. Only the unabsorbed light illuminates the object; in addition to losses due to the object itself, further losses are due to reflections, so that the backward beam forming the image is only a fraction of the direct beam. This suggests that selecting objects that are conveniently shiny or diffusive is best; dark objects are unlikely to produce good results.

Stability is also a problem in reflection holography, due to the extremely fine fringes ($\lambda/2$ spacing) that are to be recorded in this case. The mounting of figure 5 is, however, fortunate in this respect, since the overall structure with components one on top of the other is intrinsically very stable. To reduce the risk of residual vibrations, it is advisable to mount the set-up on an antivibration table; if such a table is not available, working in the basement directly on the floor is a valid alternative.

To proceed with recording, the room should be darkened. An unexposed plate is taken from the store box and conveniently positioned on the two-mirror structure. The exposure is taken by removing the beam blocker for a few seconds. Although the exposure time can be derived from the specifications of the holographic material taking into account the actual beam intensity, problems related to chemical processing and to material ageing make such data only indicative; the best exposure time is usually determined by trial and error ($\sim$4 s in our case). After exposure, the plate is stored in a box for later processing, and the light can be switched on again.

4. Processing and viewing a hologram

The object we selected for demonstration is the pencil sharpener shown in figure 2. As to the holographic material, we used 8E75 HD NAH 2.5″ × 2.5″ plates by Agfa-Gevaert. Although this type of plate is no longer available on the market, other equivalent types can be found by a quick search on the Web. Exposed plates were wet-processed in a dark room by the so-called

[2] See, for example, [2], chapter 7.

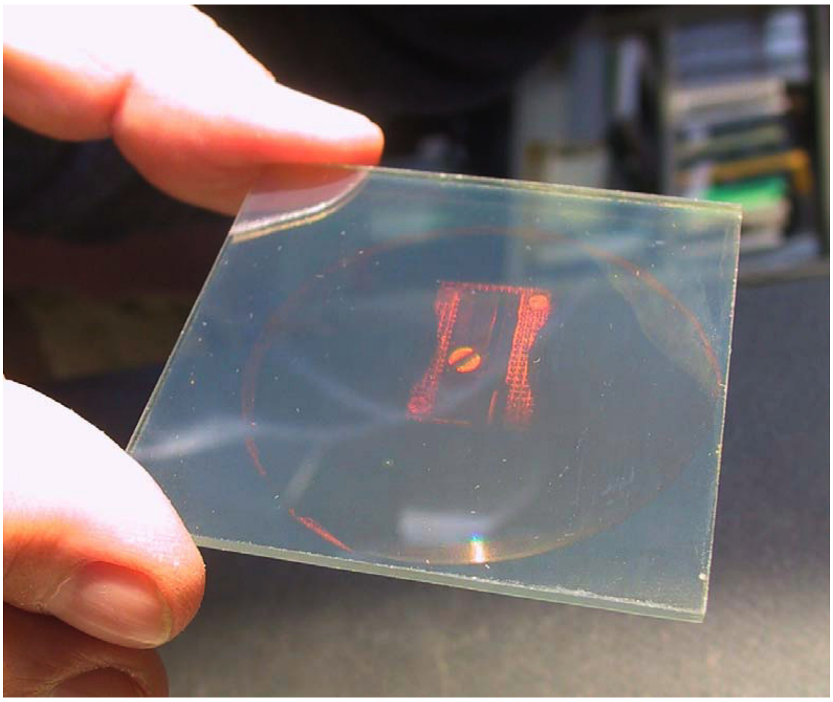

Figure 6. Example of a real holographic image reconstructed after the recording process described in the text.

Pyrochrome developer and bleach system [11]. Chemicals should be prepared, handled and disposed of with care; in case of doubts or limited knowledge, the help of a colleague with experience in chemistry should be sought. Detailed directions on the processing procedure can be found in [11].

After plate processing and drying, the reconstructed image can be viewed directly in white light. An example of the pencil sharpener reconstructed in sunlight is shown in figure 6. The image can be viewed and pictured as a true object around 360°. As with the real image shown in figure 2, the elevation angle should not exceed the value originally set by the mirror geometry. Although the photograph tends to flatten the scene, by visual observation the object appears to hover again on the plate, as did the real image on the two-mirror system.

5. Conclusions

We have presented an optical set-up and a procedure to record a real-image reflection hologram in a single step. The experiment is straightforward but, in addition to optical components of common use in a laboratory at undergraduate level, it requires a few specific objects such as the two-mirror system, the holographic plates and the chemicals for processing to be provided. It is then suggested for an advanced laboratory course, for example, as a complement to electromagnetism or as a special project that can be coordinated by a pool of teachers with appropriate competences. As to educational content, the experiment offers the opportunity of reviewing a series of basic concepts and phenomena that concur to produce the final result.

The appeal in terms of wonder and interest is effective and can motivate students to undertake the effort.

Acknowledgment

PKB-B acknowledges support of the International Centre for Theoretical Physics (ICTP), Trieste, Italy, under the TRIL Program.

References

[1] Gabor D 1948 A new microscopic principle *Nature* **161** 777–80
[2] Collier R J, Burckhardt C B and Lin L H 1971 *Optical Holography* (New York: Academic)
[3] Elings V B and Landry C J 1972 Optical display device *US Patent* 3647284 (7 March)
[4] Molesini G 2005 The lens equation revisited *Phys. Educ.* **40** 151–4
[5] Sieradzan A 1990 Teaching geometrical optics with the 'optic mirage' *Phys. Teach.* **28** 534–6
[6] Torroba R, Rabal H J and Garavaglia M J 1986 One-step rainbow holography using a spherical mirror *Appl. Opt.* **25** 3288–90
[7] Vannoni M, Greco V and Molesini G 2001 One-step 360° rainbow holography with two spherical mirrors *Appl. Opt.* **40** 633–5
[8] Denisyuk Yu N 1962 Photographic reconstruction of the optical properties of an object in its own scattered radiation field *Sov. Phys.—Dokl.* **7** 543–5
[9] Kogelnik H 1969 Coupled wave theory of thick hologram gratings *Bell Syst. Tech. J.* **48** 2909–47
[10] Tramannoni F and Matteucci G 2006 Basic experiments of physical optics presented with a modified version of the Michelson interferometer *Eur. J. Phys.* **27** 1267–75
[11] www.holoprint.com/articles/holosphere/pyrochrome.html