Pseudoscopic imaging in a double diffraction process with a slit: Critical point and experimental checking

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Abstract

Pseudoscopic (inverted depth) images that keep a continuous parallax are shown to be possible due to a double diffraction process intermediated by a slit as a consequence of a simple symmetrical process object-image. One diffraction grating directing light to the slit acts as a wavelength encoder of views while a second diffraction grating decodes the projected image. The process results in the enlargement of the image under common white light illumination, up to infinite magnification at a critical point. This point is shown to correspond to another simple symmetry object-observer. The system can be considered as a magnifier instrument, having a definite focal length value although no curvature is present in it. Results are available in video through internet. We developed a theory which accounts main ray directions only, and made measurements selecting wavelengths by means of interference filters to compare with experience, in good agreement. We also show the existence of orthoscopic (normal depth) images within the same system, constituting a direct image system whose appearance resembles a holographic image. It can be mounted with plastic diffraction gratings available at science shops, so that any person with minimal skill can experience the new properties of diffractive white light imaging.

Introduction

Refractive or reflective optics cannot render a large parallax field due to aberrations. Depth inverted images are uncommon [1] . After the development of holographic images it was possible to appreciate the benefits of having images that may render a wide field of view while keeping a continuous parallax, allowing the observer to "look around" the scene to obtain the maximum of its visual information. Holography and diffractive imaging are performed exclusively under monochromatic light or through some process that renders the final image monochromatic at least over the horizontal field of view. But diffraction can be combined with a simple imaging process to obtain white-light images for binocular viewing. We demonstrated in two previous papers [2], [3] that the ability of wavelength-encoding a continuous sequence of views may easily be obtained by simple diffraction at a grating and stated that it may also be decoded at a double diffraction process [4], [5] intermediated by a lens and a slit. We employed a lens at the symmetry center in [4] in order to get more luminosity and sharpness, at the expense of a more complicated ray-tracing problem and a reduced focal depth. By elliminating the lens now, leaving a simple thin vertical slit, we have the setup of Fig.1 corresponding to a single object point.

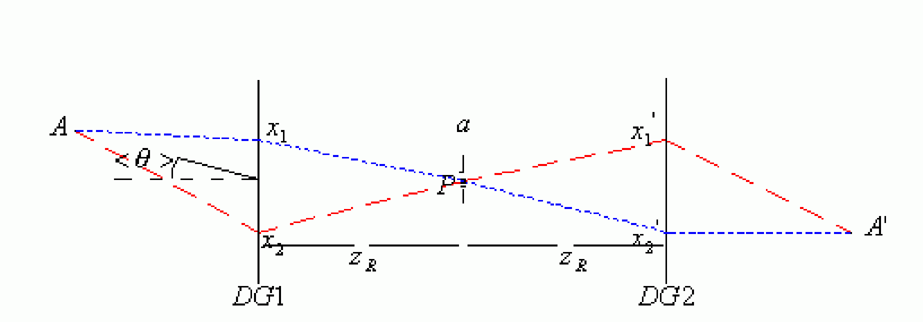

Figure 1: Ray-tracing for the symmetrical image of a point white-light object.

Our system consists of two identical diffraction gratings DG1, DG2, symmetrically located at both sides of an aperture a as shown in Fig.1. The plane of the figure corresponds to a horizontal plane containing the center P of the aperture, while the lines of the grating are in a vertical direction. An object of white or gray tonality is illuminated by common white light diffusing at a very wide angle, such as, for example, from point A. We consider the part of the beam reaching the grating, which, after diffraction, travels toward the aperture.

A second diffraction grating symmetrically located in respect to the slit is the natural way of decoding the light distribution previously coded in the first diffraction process. Symmetry properties are enough to demonstrate the generation of a pseudoscopic image, illustrated in Fig. 2 for two object points.

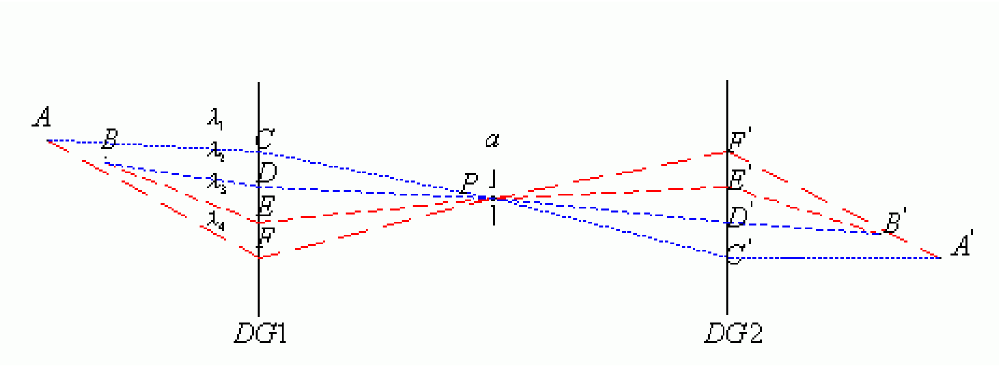

Figure 2: Ray-tracing scheme for the depth inverted image.

This kind of inverted depth image was only known from stereo photographic or holographic processes but not known in diffractive optics. Another property that can be so explained is the presence of a critical point, where an object appears with infinite magnification. The simmetry in this case is based on the viewpoint of the observer:

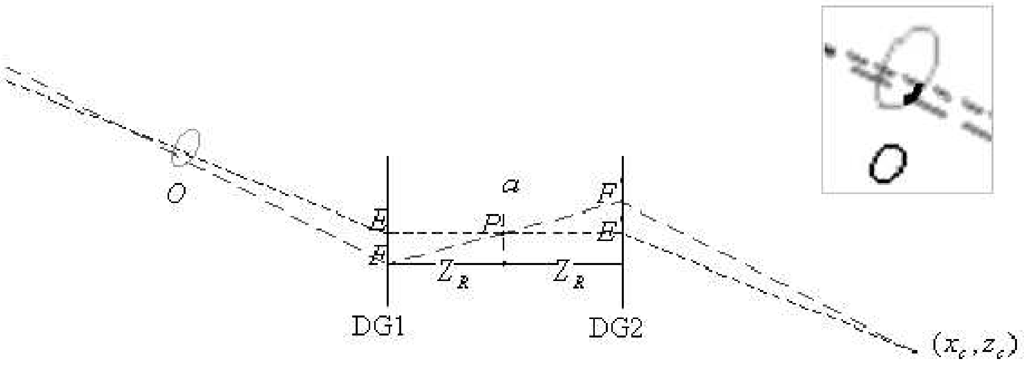

Figure 3: Ray-tracing scheme showing object field of view.

The detail in the upper right shows how the field of view dependes on the distance of the object.
More possibilities were evident in our experience: orthoscopic images clearly evident to the observer at the symmetric diffraction order of the second grating that will be described elsewhere. There is also an interesting similarity between our system presented at this meeting twelve years ago [4] and more recente developments of diffracting optics for space telescopes [6].

Experimental Setup

We employed two plastic embossed holographic transmission gratings of the same type, commercially available for architectural or educational purposes, with 533±5 lines/mm sandwiched between two glass plates 2 mm thick. Their effective area employed was less than 60 mm (H) x 40 mm (V). Undulations were evident on both, which prevented us from using their second diffraction order, where light beams appeared distorted. They were located 600±2 mm apart in parallel position and a vertical black paper slit 0,7±0,15 mm wide was in between both gratings. Parallelism of the gratings planes was verified to better than ±1 mm by making coincident reflections of a diode laser beam which traversed the slit, impinged on both gratings and returned to the laser exit. Photographs were made by a analog camera SONY video 8 Handy cam camera connected to a INTEL CS430 web camera whose only purpose was to act as a capture digital converter. It was connected to a Pentium I computer to get 240 x 320-pixel resolution.

Results and Discussions

We used as a first object the luminous and almost straight thin filament from a 300 W halogenous lamp 85±1 mm millimeters long inclined with its higher extreme being closer (230 mm) to the grating than its other extreme (280 mm). A point object was positioned at the image position, where it appeared together with the upper point when the observer moved his head transversally, and the same was done for the lower point, verifying the depth inversion of the image relative to the filament, and the same length for both. The camera was at 1,015 mm and we found the viewpoint that shows the filament in a frontal view. It corresponded to a blue wavelength (**Fig.6**-left-hand side) and was in agreement with our calculations. We also photographed the viewpoint corresponding to red (**Fig.6**-right-hand side). The presence of parallax is evident from the change in inclination, and the photograph can eventually be used to make a stereo pair.

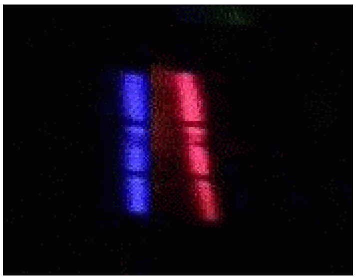

Figure 6: Two view of a straight filament corresponding to a horizontal displacement of the camera.

From the previous viewpoint which shows the image in red, we then filtered the light by interposing interference filters in its path, to get parts of the image resulting as vertical strips. It appears that each vertical strip of the image corresponds to a well defined wavelength bandwidth.

As a second object [7] we used a set of three small filament lamps, of the kind employed for illuminating car panels. The filaments were 2 mm long, facing towards the grating. They were arranged in such a way that two of them had only different vertical coordinates, while the third one had a smaller distance to the grating than the others. The situation for three viewpoints when the camera moved equal distances from left to right.is the following: At lefthandside position, the two vertically aligned points appear in green, and the other point in red. At center position, the two points are in light blue, and the other in light red. At righthandside position the formerly light blue points became in deep blue, and the other point appears now in green [8].

As a third object, we used a halogeneous 50 W lamp with a parabolic 46 mm diameter faceted reflector behind it, constituting an extended object. The image compared to the image of the object itself, as viewed from the same distance which the light from the object traversed to form the image, appears horizontally alongated [7]. The horizontal angular extension of the image was close to that of the object, but not allowing to see the whole object. By displacing the second grating to a double distance from the slit (600 mm) we saw, at almost the same distance from the slit but 80 mm displaced laterally, an enlarged horizontal field of view for the scene, shown in **Fig.10**.

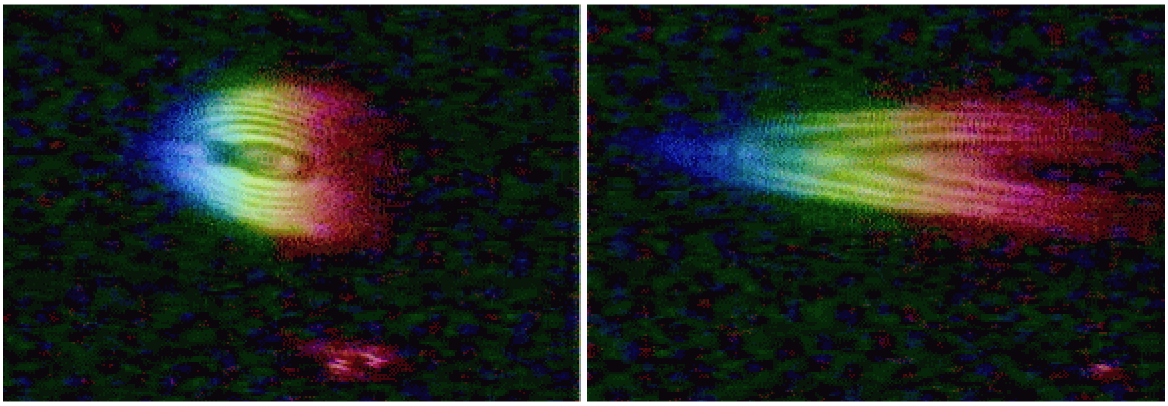

Figure 10: Horizontally enlarged object field of view. Left: symmetrically located gratings. Right:second gratind at double distance from the slit.

We can see that the elliptical deformation of the image indicates horizontal magnification. The horizontal magnification can be evaluated as greater than x4. As a fourth object we employed the shadow of a paper clip located against a diffusing background. The clip was made of wire 1 mm thick and we employed its asymmetric shape to identify the inversion properties corresponding to the dispersion direction. The background remained fixed at 1,680 mm distance, while the clip was located between the system and the critical point at 960 mm, at the critical point at 1,270 mm, and farther from the critical point at 1,540 mm, respectively **Fig.11**

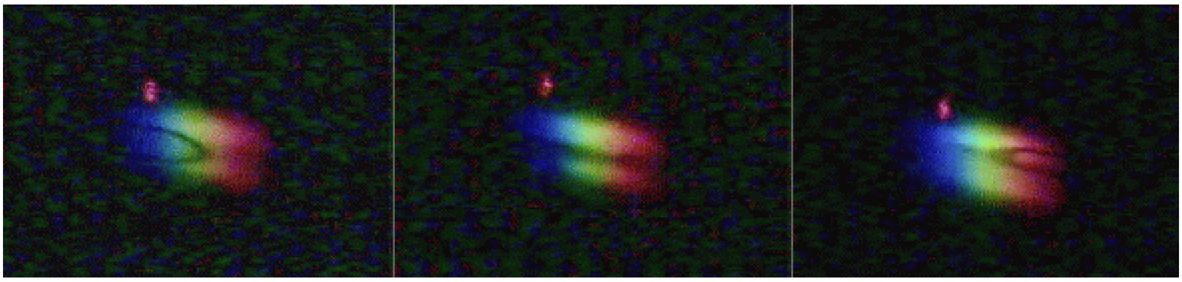

Figure 11: Sequence of object positions at increasing distances showing the inversion of the image. Left: at nearer distance. Center: farther, at the critical position, Right: even farther, showing lateral inversion [9].

Although the diffracting elements acts in one direction only and does not project an image, it seems possible to have a two-dimensional equivalent by using circular diffraction gratings, which could project images on a plane.

Conclusions

We demonstrated a new way of generating a pseudoscopic image directly from an object, which does not need refracting elements. Also, that image enlargement is possible in one direction by means of purely diffractive elements and using the whole spectrum of white light. An aperture which gives a large field for viewpoints comes from a diffractive element whose construction and manipulation is much easier than that of conventional optical elements. The reproduced light field is very similar to the original object field where no magnification distortions are present, even in a longitudinal direction. A focalisation property at infinite magnification was demonstrated. We showed that white light 3D imaging through diffractive optics renders images with an interesting resemblance to holographic images. We have an interesting possibility for increasing the aperture of an optical system because diffraction gratings can be made to deflect light at very large angles generating large angular aperture values.

Acknowledgements

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[8] See video:
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[9] See video:
http://www.ifi.unicamp.br/~lunazzi/F809/videos/Inversao.avi