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3D DISPLAY SYSTEM BASED ON HOLOGRAPHIC SCREEN AND MICROCOMPUTER-DRIVEN GALVANOMETERS

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Abstract: A system based on a 65cm x 35cm holographic screen is described as being capable of displaying three-dimensional figures with continuous horizontal parallax using a microcomputer and three galvanometric mirrors.

Key words: 3D display, holographic optical elements, diffractive optics, CAD, computer generated holography.

Direct volume display devices [1] need massive moving components [2,3] and cannot generate straddling figures because they cannot be shown outside of the protective housing. Real-time computer-generated holography [4] requires enormous computing capability and generates very small images.

The authors [5,6] have described the possibility of displaying under white light computer generated 3D figures with continuous horizontal parallax without making a hologram. The **X**,**Y** position of each voxel (volume element) of the figures is determined as in a laser show, i.e. by deflecting a light beam through two galvanometric mirrors. The **Z** coordinate is determined in two steps: a **Z**-controller first encodes it by means of a variable chromatic dispersion applied to a white-light beam, then a holographic screen decodes it finally placing the voxel in its three-dimensional position.

We describe here a system capable of generating volume figures under white light based on diffraction encoding and decoding. The number of moving components can be reduced to three galvanometric mirrors.

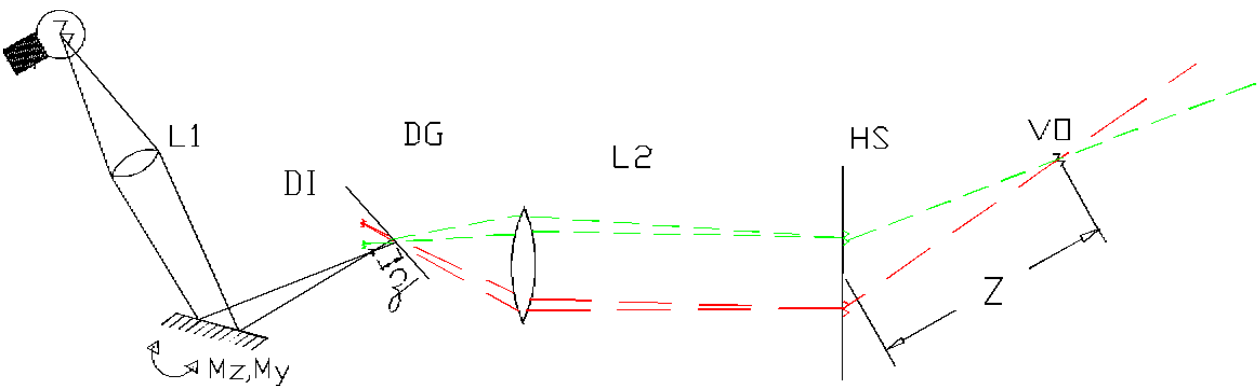

Fig. 1 - ***Determination of Z based on a diffraction grating.***

As shown in **Fig.1**, a lens **L1** produces a small real image of a lamp filament, rapidly positioned by tilting the mirrors **Mz** and **My**. This movement of the filament image occurs approximately within a plane that crosses the diffraction grating **DG.** Object points presented to the diffraction grating are images in fact, so allowing the z coordinate to change easily from positive to negative thus generating final straddling images. The position of the images diffracted by the grating (**DI**) constitute a spectral sequence [7]. This sequence is equidistant from the illuminated region on the grating, as follows: considering the waves composing the white-light beam as being parabolic, incident at an angle θ and diverging at a distance $z = z_0$ from the grating, their expression is:

$$\Psi_i(x) = \exp(ikx \sin\theta) \exp(-ikx^2/2z_0) \qquad \textbf{(Equation 1)}$$

where unitary amplitude is assumed. The spatial frequency of the grating is **ν** along the spatial coordinate **x** giving a transmitance expressed as:

$$t(x) = 1 + a\cos k\lambda \upsilon x \qquad \textbf{(Equation 2)}$$

When the light traverses the grating the diffracted images are obtained by the multiplication of the incident beam by the term corresponding to diffraction along the lens direction. The result is:

$$\Psi_d(x) = \frac{a}{2}\exp(ik\upsilon x(\lambda_R - \lambda))\exp(-ikx^2/2z_0) \qquad \textbf{(Equation 3)}$$

corresponding to a beam diverging from a distance $\mathbf{z_0}$ chromatically spreaded according to the classical diffraction equation of a grating[1]. The farther the image is from the grating the more the spectral dispersion increases. The lens **L2** projects an image of **DI** onto the holographic screen **HS**. **HS** then

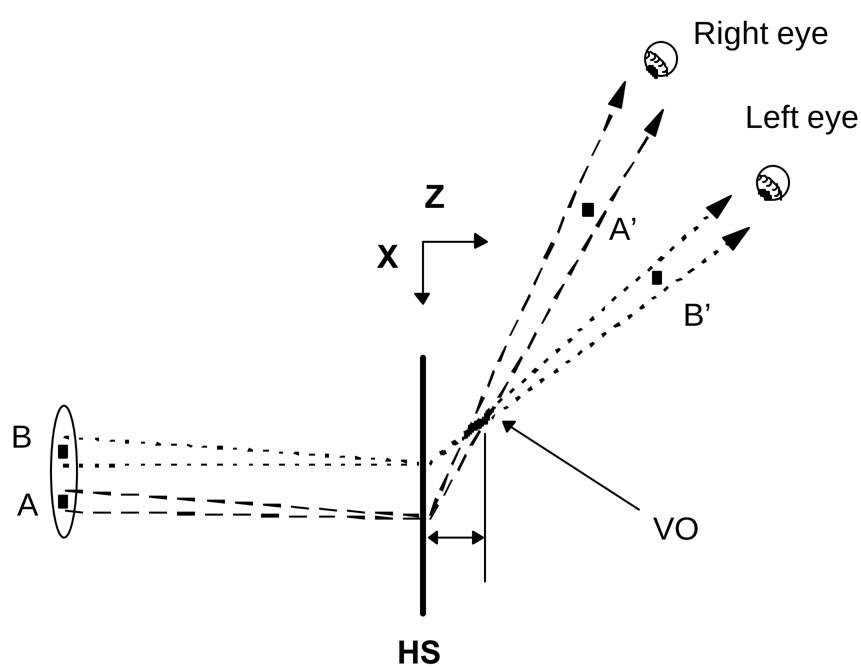

Fig. 2 - ***Spectral decoding of depth (z) performed by HS. For simplicity, only two wavelengths were drawn.***

decodes the spectral image dispersion into the **Z**-coordinate of the voxel **VO**.

[1]This reasoning is also valid for converging incident waves.

The holographic screen is a special diffractive lens [8] that receives white light from a projecting lens, as described in **Fig.2**. It was built in such a way that, for example, red rays passing through **A** also pass through **A** (focus for red wavelength) while blue rays passing through a near point **B** pass through **B** (focus for blue wavelength).

This occurs due to $\nu_S(x)$, the spatial frequency function of the holographic screen, described by the equation:

$$\nu_S(x) = \frac{1}{\lambda_0}\left[\frac{D-x}{\sqrt{(B^2+(D-x)^2)}} - \frac{x+A}{\sqrt{(C^2+(x+A)^2)}}\right] \qquad \textbf{(Equation 4)}$$

where A,B,C and D are constants geometrically determined in the setup and λ_0 is the wavelenght employed during the exposure.

Similarly to the observation of a real point, the observers' eyes receive different stereo-pairs when looking around the activated voxel **VO**. The intersection of the beams takes place further away when the width of the projected spectrum is larger, and it is zero when the width is null. The voxel's **Z** coordinate is thus defined from the spectrum width that impinges **HS**.

In this scheme the position of the mirror **Mz** determines the z coordinate but generates a lateral displacement to be compensated. The compensation can be performed by an aditional galvanometric mirror located immediately after lens **L2**. This mirror can also introduce the appropriate **X** value of the voxel and for simplicity was not introduced in our experience.

Comparing to a 2D conventional display, we can say that the only additional moving part is the **Mz** mirror. This possibility allows the system to generate 3D images at speed rates compatible with conventional 2D vector displays.

The experiment was made by imaging the filament of a halogen flash lamp through a zoom objective lens of 52mm aperture, 4.5 f-number and focal length range of 80 to 205mm, located at 485mm from the lamp.

A rotating mirror was used to produce a luminous ring. The mirror was fixed to the axis of a small motor rotating at 50 Hz and making an angle of 3^{o} with the rotation axis, and was placed at a distance of 205mm from the first lens. The ring reached a 1300 l/mm photoresist holographic diffraction grating at 265mm from the mirror having a diameter of approximately 10mm. A second zoom objective lens of 45mm aperture f-number of 2.8 and 135mm focal length was positioned at a distance of 200mm after the grating. The optical axis of this objective was aligned to be parallel to the diffracted beam, approximately at 45^{o} in relation to the normal of the grating. A holographic screen of dimensions 63cm

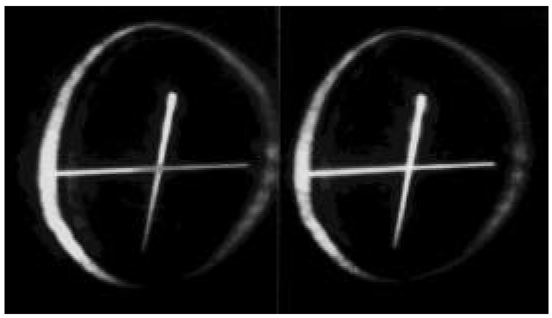

Fig. 3 - ***Stereo photographic pair showing the generated figure.***

x 35cm was placed at 1380mm from the second objective.

The angular viewing zone allowed the figure to be observed sideways, as in a hologram. It extended over 22cm laterally, at 1m distance from the screen. As expected, the final image was a luminous tilted ring suspended in air, straddling **HS** as shown in **Fig.3**. This stereo-pair was obtained from arbitrary positions within the viewing zone laterally separated by 7 cm. An X-shaped luminous mark was projected on the screen to be used as a reference for parallel-eye viewing. The result encouraged us to improve the experimental conditions, and further developments on the displaying of wire-frame figures in a volume of 36 x 65 x 90cm by using three microcomputer-driven galvanometric mirrors will be published elsewhere.

It is possible to use a spatial light modulator instead of galvanometers to control **X**,**Y** coordinates. The association of this technique to **Z**-scanning will allow the generation of surfaces and solids.

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