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(54) HOLOGRAPHIC METHOD AND APPARATUS



(71) We, KARL VOCKENHUBER of 118 Potzleinsdorferstrasse, Vienna 18, Austria, and RAIMOND HAUSER, of 2 Goldegg-Gasse, Vienna 4, Austria, both of Austrian nationality, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to holography and is more particularly concerned with using a holographic process for establishing identity between consecutive presentations of two superficially similar objects or the same object under different conditions.

15 In accordance with one aspect of this invention a holographic method of establishing identity between two superficially similar presentations of an object or between presentations of two different objects, comprises irradiating a first presentation with coherent light; passing reflected light from the first presentation through an aperture stop and projecting it onto a light-sensitive surface simultaneously projecting onto the surface a reference beam of coherent light which is focussed to a point substantially conjugate with the plane of the stop; the light-sensitive surface having means for scanning it electrically to provide an electrical output signal of the pattern of illumination of the surface and being adapted to store a holographic first image produced by the interaction of the reference beam with the picture on the surface; replacing the first presentation by the second presentation to project reflected light therefrom onto the surface and thereby produce a holographic second image with the reference beam; effectively superimposing (as herein defined) the first and second images and producing therefrom a television picture in which areas of difference between the two images appear as

different levels of brightness in the television picture.

The invention also includes test apparatus 45 suitable for establishing identity between two superficially similar presentations of an object or between presentations of two different objects, comprising: a test position; a source of coherent light arranged to irradiate the test position; an optical system and apertures stop for projecting light reflected from an irradiated portion of the first presentation when under examination at the test position, towards a light-sensitive surface; an optical arrangement for projecting onto the surface a reference beam of coherent light after having focussed it to a point which is conjugate with the plane of the aperture stop; means for storing a holographic first image thus formed on the surface; means for effectively superimposing (as herein defined) the stored image and a subsequently made further holographic second image obtained by replacing the first presentation at the test position by the second presentation; and, television equipment for producing from the two images a picture in which areas of dissimilarity between them contrast with areas of identity. Suitably the surface is provided by the screen of an electron beam scanning tube. Because of the modulation transmission properties of electron beam scanning tubes, the local intensity distribution of the interference pattern of the hologram should have spatial frequencies which are as low as possible and are uniformly distributed throughout the image area to enable a uniform quality of the modulation transmission to be obtained throughout the scanning process. 80

The focussing of the reference beam to a point conjugate with the plane of the aperture stop results in a distribution of spatial frequencies which is suited to the modulation

transmission properties of an electron beam scanning tube. As a consequence, the high requirements as to the precision of the superimposition are met, particularly if a vidicon storage tube is used to store the first image.

The term "effectively superimposing" is used throughout the specification to define a process in which the superimposition of the two holographic interferometric images may physically occur i.e. one light image superimposed over the other or instead the two images may be separately scanned at different times and the video signal obtained from the first scan stored on a video tape and then compared with a video signal generated during the second scan so that the same information, i.e. a difference in the intensities of identical areas of the two holograms, is obtained in both cases.

An advantage of the invention is that no optical reconstruction of the first holographic interferometric image is necessary and thus the requirements as to precision as well as time in making a comparison are much reduced.

The invention will now be explained in more detail, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 shows an arrangement for producing the primary interferences of a hologram on a screen, the reference beam being focussed near the centre of the aperture stop;

Figure 2 shows an arrangement in which the reference beam is focussed at the centre of the aperture stop;

Figure 3 illustrates the intensity distribution for the reference beam;

Figure 4 illustrates the intensity distribution for the object beam;

Figure 5 illustrates the intensity distribution of the superimposed images with a phase displacement corresponding to an odd multiple of π ;

Figure 6 illustrates the corresponding intensity distribution with a phase displacement corresponding to an odd multiple of π ; and

Figure 7 is a diagrammatic view showing an optical arrangement for carrying out the invention.

As previously stated, owing to the modulation transmission properties of electron beam scanning tubes, the local intensity distribution of the interference pattern of the hologram should have spatial frequencies which are as low as possible and are uniformly distributed throughout the image area so that a uniform quality of the modulation transmission by the scanning process is ensured. As shown in Figure 1, this is accomplished in that rays 21, 22, 23, 24 coming from the object and serving to produce an image plane hologram pass through an optical system, of which only an aperture stop 27 is diagrammatically shown. On a screen 28, the object rays 21—24 are caused to interfere with reference rays 25, 26. The reference rays 25, 26 are focussed at

a point 29 near the plane of the aperture stop 27. It is apparent that the reference rays 25, 26 include angles α_1 and α_2 , respectively, with the marginal rays 21, 22, and angles β_1 and β_2 , respectively, with the marginal rays 23, 24. These angles limit the bright-dark frequencies of the interference pattern, and it is clearly apparent from Figure 1 that these angles differ only slightly from each other.

Even smaller differences between the angles and the lowest frequencies in the intensity distribution will be obtained if, in accordance with Figure 2, the reference beam is focussed with the marginal rays 25, 26 and a central ray 30 at the centre of the aperture stop 27. In this case, the angles included by the object rays 21—24 and 31, 32 and the associated reference rays 25, 26, 30 are approximately as large as one-half of the aperture angle, throughout the image area. The aperture stop 27 may then be adjusted to control the angle between the object rays and reference rays so as to adapt the bright-dark frequencies of the resulting interference pattern to the modulation transmission properties of the scanning tube which is employed.

If the local amplitude and phase distribution of the object wave front in the scanning plane is designated by

$$a_{(x,y)} \exp(i(\omega t - \varphi_{(x,y)})), \quad 95$$

that of the reference wavefront by

$$b_{(x,y)} \exp(i(\omega t - \psi_{(x,y)})), \quad 100$$

where x and y are the coordinates of the scanning area, $\varphi_{(x,y)}$ and $\psi_{(x,y)}$ are the local phases for $t=0$, and ωt the time base phase response of the waves, the spatial intensity distribution $J_{(x,y)}$ in the image plane can be shown to be defined as:—

$$I^2 = a^2 + b^2 + 2ab \cos(\varphi - \psi)$$

where the suffices (x,y) are omitted for the sake of simplicity. 105

Information as to the interaction or interference between the object beam and reference beam is contained only in the last term of this expression, namely, 110

$$2ab \cos(\varphi - \psi).$$

The term b^2 defines the intensity distribution of the reference wave front; this distribution is generally constant, as a rule, throughout the image area (Fig. 3). The term a^2 defines the intensity distribution of the object wave front, which with light-diffusing objects has the granulation which is typical for coherent radiation. This is a statistically varying intensity distribution, which is due to the interference of the object rays with each other 115
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and for this reason is also independent of the aperture (Figure 4).

When changes are made in the object, the object wave front in the image plane changes.

5 In the case of small changes in the object, the changes $c_{(x,y)}$ of the amplitude distribution of the object wave front in the image plane may be defined with good approximation as a displacement of the original amplitude distribution:

$$c_{(x,y)} \cong a_{(x+\Delta x, y+\Delta y)}$$

where the displacement parameters Δx and Δy result from the local displacements of the object in the directions parallel to x and y and from the lateral magnification.

$$30 \quad J_{\text{total}} = 2(a^2 + b^2) + 2ab(\cos(\varphi - v) + \cos(\varphi - v + \Delta\varphi))$$

It is apparent from this equation that the interference terms are eliminated for

$$\Delta\varphi = (2n + 1)\pi$$

and that they are a maximum where

$$35 \quad \Delta\varphi = 2n\pi.$$

For this reason, those parts of the object which have been changed so that the coherent radiation which has been phase-displaced by an odd multiple of π have an intensity distribution which is only slightly modulated by the granulation of the object beam (Figure 5), whereas those parts for which the phase displacement amounts to an even multiple of π have an intensity distribution which is highly modulated by the interference terms (Figure 6).

Figure 7 shows apparatus for making use of the invention and in which a light beam 2 emitted by a laser 1 is divided by a partially reflecting mirror 3 into an object beam 4 and a reference beam 5. By an auxiliary optical system 6, the object beam 4 is diverged and directed onto an object 7, which reflects a beam 8 to a main optical system 9. The latter comprises preferably an adjustable aperture stop 10, which eliminates the marginal rays which come from a point P of the object and are at an excessively large angle. In this way, the angle included by the marginal rays of the beam which is reflected by the object 7 and the subsequently introduced reference beam 5 may be selected to be so small that the resulting bright-dark frequencies correspond to the resolving power of a television camera tube. From the main optical system 9, the beam 8 is transmitted by another partial reflecting mirror 11 onto the screen of a television camera tube 12.

The reference beam 5 is directed by a deflecting mirror 13 and an auxiliary optical

Where Δx and Δy are very small compared to the mean spacings of the intensity maxima and minima of the granulation, further approximations can be made resulting in equations from which it can be shown that the interference of the object wave front with the unchanged reference beam results in an intensity distribution $2^J(x,y)$ in the image plane defined as:—

$$2^J = a^2 + b^2 + 2ab \cos(\varphi - v + \Delta\varphi) \quad 25$$

Where $\Delta\varphi$ is the spatial phase displacement which is due to the change in the object. A superposition of the two image plane holograms results in an intensity distribution:

system 14 and is focussed in a plane 14a, which is conjugated with the plane of the aperture stop 10 of the main optical system 9 and is subsequently also directed to the partially reflecting mirror 11, which lies in the light path of the light from the main optical system 9 so that the reference beam also reaches the screen of the television camera tube 12. Because the reference beam is focussed in the plane 14a, which is conjugated with the plane of the plane 10, the reference beam appears to come from the centre of the main optical system 9. By a change of the aperture by means of the stop 10, the angle included by the marginal rays of the beam 8 and the beam 5 can be changed. Because the reference beam appears to come from the centre of the optical system, it virtually bisects the angle which is concluded by the outermost marginal rays. Where it is desired to render visible only the bright-dark frequencies of the resulting hologram, the pulses delivered by the television camera tube 12 may be applied directly to a television receiver 15. For the interferometric examinations, however, the television camera tube 12 consists preferably of a vidicon storage tube; on the screen of which the hologram of the object 7 is produced first. The characteristics of the object, which may consist, e.g., of a rubber tyre to be examined, are then changed. For instance, the tyre is inflated. With the means shown in the drawing being in the same arrangement, a second hologram which is superimposed on the stored hologram is now produced on the screen of the vidicon storage tube and a.c. signals are produced as a result of scanning the superimposed hologram and are applied to the receiver 15.

By the scanning operation, the spatial industry modulations are changed into time-base modulations of the video signal. Three evaluation methods may be adopted to enable a distinction between highly and slightly modulated image portions to be obtained and thus a good

contrast on the television receiver. These methods are as follows:—

1. The gradation characteristic of the image reproduction is controlled so that only the absolute intensity minima appear bright. In this case, the less modulated image portions appear dark and the highly modulated ones have brightened patches.

2. The gradation characteristic is controlled so that only the absolute intensity minima appear dark. In this case, the slightly modulated portions appear bright and the more highly modulated ones have darkened patches.

3. The two holograms are separately scanned and one is stored, for example, on a video tape which is played back in synchronism with the scanning of the second hologram. Thus two streams of pulses are obtained which are continuously compared and which are identical as long as the two holograms are identical. The difference in frequencies resulting from difference in the two holograms are selectively amplified by a non-linear amplifier, which may be frequency selective if required, and are applied as an input signal to the television receiver. In this way, differences in modulation depth between the two superimposed hologram video signals are changed into brightness differences.

Whereas the two first-mentioned methods are simple, they may result in patchy images and may be used only with objects of uniform brightness.

These disadvantages are largely eliminated with the third method, which may be considered as an electronic superimposition of the two holograms.

WHAT WE CLAIM IS:—

1. A holographic method of establishing identity between two superficially similar presentations of an object or between presentations of two different objects, comprising: irradiating a first presentation with coherent light; passing reflected light from the first presentation through an aperture stop and projecting it onto a light-sensitive surface simultaneously projecting onto the surface a reference beam of coherent light which is focussed to a point substantially conjugate with the plane of the stop, the light-sensitive surface having means for scanning it electrically to provide an electrical output signal of the pattern of illumination of the surface and being adapted to store a holographic first image produced by the interaction of the reference beam with the picture on the surface; replacing the first presentation by the second presentation to project reflected light therefrom onto the surface and thereby produce a holographic second image with the reference beam; effectively superimposing (as herein defined) the first and second images and producing therefrom a television picture in which areas of difference

between the two images appear as different levels of brightness in the television picture.

2. The method claimed in claim 1, in which the aperture stop size is adjusted to produce maximum contrast in the television picture between said areas and the remainder of the television picture.

3. The method claimed in claim 1 or claim 2, in which the light sensitive surface is the screen of an image storage tube.

4. The method claimed in claim 1 or claim 2, in which the holographic first image is stored on a video tape.

5. The method claimed in any one of the preceding claims, in which electrical signals from which the television picture is to be formed are passed through a non-linear amplifier which selectively amplifies those signals which are significant of the areas of difference between the two images to enhance the contrast of the television picture.

6. Test apparatus suitable for establishing identity between two superficially similar presentations of an object or between presentations of two different objects, comprising: a test position; a source of coherent light arranged to irradiate the test position; an optical system and aperture stop for projecting light reflected from an irradiated portion of the first presentation, when under examination at the test position, towards a light-sensitive surface; an optical arrangement for projecting onto the surface a reference beam of coherent light after having focussed it to a point which is conjugate with the plane of the aperture stop; means for storing a holographic first image thus formed on the surface; means for effectively superimposing (as herein defined) the stored image and a subsequently made further holographic second image obtained by replacing the first presentation at the test position by the second presentation; and, television equipment for producing from the two images a picture in which areas of dissimilarity between them contrast with areas of identity.

7. Apparatus as claimed in claim 6, in which the aperture stop is adjustable.

8. Apparatus as claimed in claim 7 or claim 8, in which a partially reflecting mirror set at an angle to the optical path between the optical system and the screen serves the dual function of transmitting light from the test position towards the surface and reflecting the reference beam towards the surface.

9. Apparatus as claimed in claim 6, claim 7 or claim 8, in which the surface forms a screen of an image storage tube.

10. Apparatus as claimed in claim 9, in which the tube is a vidicon storage tube.

11. Apparatus as claimed in any one of claims 6 to 9, including a non-linear amplifier in the television equipment for selective amplification of signals fed to the television



contrast on the television receiver. These methods are as follows:—

1. The gradation characteristic of the image reproduction is controlled so that only the absolute intensity minima appear bright. In this case, the less modulated image portions appear dark and the highly modulated ones have brightened patches.

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3. The two holograms are separately scanned and one is stored, for example, on a video tape which is played back in synchronism with the scanning of the second hologram. Thus two streams of pulses are obtained which are continuously compared and which are identical as long as the two holograms are identical. The difference in frequencies resulting from difference in the two holograms are selectively amplified by a non-linear amplifier, which may be frequency selective if required, and are applied as an input signal to the television receiver. In this way, differences in modulation depth between the two superimposed hologram video signals are changed into brightness differences.

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between the two images appear as different levels of brightness in the television picture.

2. The method claimed in claim 1, in which the aperture stop size is adjusted to produce maximum contrast in the television picture between said areas and the remainder of the television picture.

3. The method claimed in claim 1 or claim 2, in which the light sensitive surface is the screen of an image storage tube.

4. The method claimed in claim 1 or claim 2, in which the holographic first image is stored on a video tape.

5. The method claimed in any one of the preceding claims, in which electrical signals from which the television picture is to be formed are passed through a non-linear amplifier which selectively amplifies those signals which are significant of the areas of difference between the two images to enhance the contrast of the television picture.

6. Test apparatus suitable for establishing identity between two superficially similar presentations of an object or between presentations of two different objects, comprising: a test position; a source of coherent light arranged to irradiate the test position; an optical system and aperture stop for projecting light reflected from an irradiated portion of the first presentation, when under examination at the test position, towards a light-sensitive surface; an optical arrangement for projecting onto the surface a reference beam of coherent light after having focussed it to a point which is conjugate with the plane of the aperture stop; means for storing a holographic first image thus formed on the surface; means for effectively superimposing (as herein defined) the stored image and a subsequently made further holographic second image obtained by replacing the first presentation at the test position by the second presentation; and, television equipment for producing from the two images a picture in which areas of dissimilarity between them contrast with areas of identity.

7. Apparatus as claimed in claim 6, in which the aperture stop is adjustable.

8. Apparatus as claimed in claim 7 or claim 8, in which a partially reflecting mirror set at an angle to the optical path between the optical system and the screen serves the dual function of transmitting light from the test position towards the surface and reflecting the reference beam towards the surface.

9. Apparatus as claimed in claim 6, claim 7 or claim 8, in which the surface forms a screen of an image storage tube.

10. Apparatus as claimed in claim 9, in which the tube is a vidicon storage tube.

11. Apparatus as claimed in any one of claims 6 to 9, including a non-linear amplifier in the television equipment for selective amplification of signals fed to the television

receiver and significant of an area of dissimilarity between the two images.

12. The method claimed in claim 1 and carried out substantially as described with reference to the accompanying drawings.

13. Apparatus as claimed in claim 6

arranged and adapted to operate substantially as described with reference to Figure 7 of the accompanying drawings.

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