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(54) **Optical correlator.**

(57) A joint transform correlator in which a servo-feedback system (18) is included which employs the correlation signal output to electronically modify the representation of the 'archetype' in the reference scene portrayed in one of the spatial light modulators (12) of the correlator to make it a closer match to any 'quarry' discovered in the investigation scene portrayed in the other spatial light modulator (11).

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OPTICAL CORRELATOR

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This invention relates to optical correlators, and in particular to optical correlation using a Joint Transform Correlator. In a Joint Transform Correlator light from a first spatial light modulator, which creates
15 a coherent light phase or contrast image, is collected by a first lens or lens system and is interfered in the Fourier transform plane with light collected by that lens or lens system from a second spatial light modulator located alongside the first. A hologram recording device
20 is located at this Fourier transform plane, and this, in its turn, is illuminated with coherent light which is collected by a second lens or lens system to form a correlation image on a two-dimensional image receiving photo-electronic transducer in the Fourier transform
25 plane of this second lens or lens system. The transducer is typically provided by a photodetector array, but at least in principle could alternatively be provided by a single large area detector whose surface is scanned to extract the image information after the manner employed
30 in certain types of video camera. For an analysis of the operation principles of a Joint Transform Correlator reference may be made to the article by D. Casasent, entitled "Optical Computing Techniques for Radar and Sonar Signal Processing", appearing in the Proceedings of
35 the Society of Photo-Instrumentation Engineers Vol.118 (1977), 100.

One of the applications of optical correlators is to determine whether a particular object, hereinafter referred to as the quarry, is present in a particular scene under investigation which will generally contain
5 other extraneous objects and/or clutter noise. If the quarry is present in the investigation scene, the correlator will normally be required to identify its location in that scene. These functions of identification and location are performed by correlating
10 the investigation scene with a reference scene that contains a reference object or archetype of the quarry.

Optical correlators perform well when there is a perfect match between quarry amongst its background 'clutter' in the investigation scene and the archetype in
15 the reference scene. In a Joint Transform Correlator the position of the quarry can be ascertained from the position of the correlation peak in the output plane at which is situated the two-dimensional transducer. However, small deviations from a perfect match between
20 quarry and archetype, such as orientational misalignments and scale variations, result in severe degradations of the correlation peak. Hitherto, a limited amount of information concerning these deviations has been extracted by performing an analysis of the shape of the
25 correlation peak; whereas the present invention is concerned with a correlation system in which the deviations are reduced by means of a servo-feedback system which employs the correlation signal output to modify the display of the archetype in the reference
30 scene so as to optimise the correlation peak.

According to the invention there is provided a joint transform correlator having first and second spatial light modulators for forming adjacent first and second coherent light phase or contrast images in the
35 input or object plane of the correlator, a dynamic hologram recorder spaced from the object plane, and an intervening first lens or lens system located such that

the dynamic hologram recorder lies in the Fourier transform plane of the coherent light images, a coherent light source for illuminating the dynamic hologram recorder, a two-dimensional image receiving
5 photoelectronic transducer, and an intervening second lens or lens system located such that the transducer lies in the Fourier transform plane of the dynamic hologram recorder, wherein the second of the spatial light modulators is adapted to be electronically controlled
10 using a servo-feedback system to change its image to maximise the sharpness of the correlation image formed on the transducer.

There follows a description of an optical correlator embodying the invention in a preferred form.
15 The description refers to the accompanying drawings in which :

Figure 1 is a schematic diagram of the correlator, and

Figure 2a and 2b depict how the correlator of
20 Figure 1 is modified to include a correction element to suppress the systematic error introduced by extraneous distortion of the wavefront of light reflected by spatial light modulators in the correlator.

The basic components of the Joint Transform
25 Correlator of Figure 1 are a first coherent light source 10, first and second spatial light modulators 11 and 12 for displaying respectively the quarry scene and the reference scene, a first lens or lens system 13, a dynamic hologram recorder 14 for the temporary storage of
30 a hologram in the Fourier transform plane, a second coherent light source 15, a second lens or lens system 16, a CCD photodiode array 17 in the detection or correlation plane, and a servo-feedback system 18 for controlling, with the output from the CCD array, the size
35 and orientation of the archetype displayed by the second spatial light modulator 12.

Associated with the first coherent light source 10, a laser, is a beam expander 19 to broaden its output sufficiently to flood the two spatial light modulators 11 and 12. These devices are of reflex rather than
5 transmission type, and hence the light from the laser 10 is directed on to the devices via a beam splitter 20. (If transmission type devices were employed the beam splitter would be omitted and the position of the laser appropriately changed.) A preferred form of spatial
10 light modulator is a liquid crystal cell matrix addressed via an active silicon backing to the liquid crystal layer. Examples of such devices are described in our Patent Specification No. 2118347A.

The dynamic hologram recorder may be a
15 degenerate four-wave mixer, for instance of the bismuth silicon oxide type. It is not necessary however, for this function for the two waves involved in 'writing' to have the same frequency as the two used for 'reading', i.e. the emission wavelength of the second coherent light
20 source 15, also a laser, is not necessarily the same as that of the first laser 10.

For the dynamic hologram recorder the choice of different wavelengths enables the use of a thermal type four wave-mixer in which a thermal pattern is created by
25 the absorption by the medium of the light of the writing wavelength, while a different wavelength, at which the medium is substantially transparent, is employed for reading so that the reading operation shall leave the thermal pattern substantially undisturbed. One class of
30 such thermal four-wave mixers is provided by the class of liquid crystal cell described in patent application No. claiming priority from UK Patent Application No. 8403228 and identified as W.A. Crossland - P.W. Ross - N. Collings 45-13-2. The second laser is, like the first
35 laser, provided with a beam expander 21 and beam splitter 22.

The CCD photodiode array is mounted in the Fourier transform plane of the dynamic hologram recorder

formed by the second lens or lens system 16. Associated with this array is support electronic hardware in the servo-feedback system 18 this hardware consisting of an A/D converter, an image memory, and a microprocessor or minicomputer.

The position of the correlation spot formed on the array 17 provides information on the location of the quarry in the scene under investigation. Normally the size of the array 17 is smaller than the joint size of the two spatial light modulators 11 and 12, and therefore some demagnification is required in the system. This is achieved by making the focal length f_1 of lens 13 larger than the corresponding focal length f_2 of lens 16. This provides a demagnification factor of f_2/f_1 .

The essence of the correlator is that, under the control of the servo-feedback system 18, the presentation of the archetype in the reference field as displayed by spatial light modulator 12 is modified to provide an optimised correlation peak at the array 17. There are many different routes by which the servo-feedback system may be programmed to achieve the optimisation.

One route is for the servo-feedback system to arrange for the displayed representation of the archetype to be first progressively rotated to find the optimum orientation, and then for magnitude to be progressively changed to find the optimum match of size.

An alternative route that is possible, provided that the spatial light modulator exhibits a good dynamic range of grey-scale, is for the different orientational perspectives to be initially presented simultaneously, rather than sequentially, by generating a superimposed composite image. The magnitude of this composite image is progressively changed to find the optimum scale match, and then the different orientations are presented in sequence to find the optimum orientation match.

The amplitude of the correlation peak falls quite rapidly with mismatch of both size and

orientation. Thus typically it may be reduced by 3dB for a misalignment of 0.2° or a scale mismatch of 0.5%. Under these circumstances there would need to be 1800 presentations of different orientation to cover every possible orientation, and 100 presentations of different scale to cover a 50% range of scale. Operation at a rate of 50 frames a second would therefore require 1 hour to go through the whole of this repertoire. The period can however, be significantly shortened by performing some form of multivariate analysis upon the shape of the correlation peak instead of relying solely upon its peak amplitude. By appropriate digital image processing techniques operating on the CCD array output it is possible to increase the size of the orientation step from 0.2° to 2.5° , and the size of the scale step from 0.5% to 5%. Under these circumstances the total orientation field is covered in 72 presentations, while the scale field is covered in 10 presentations, with the result that the whole repertoire is reduced to just under 15 seconds. For further information concerning the potential of multivariate analysis for this application reference may be made to the article by F. Merkle, entitled "Hybrid Optical-Digital Image" appearing in Proceedings of the Society of Photo-Instrumentation Engineers, Processing System for Pattern Recognition" Vol. 422 (1983), 152. Clearly further optimisation is possible for dedicated tasks. For instance, the presentation time for the orientation field can be reduced in instances where the archetype is known to have some measure of rotation symmetry.

A problem in all correlator systems is the low tolerance of the system with respect to optical imperfections of the spatial light modulators that give rise to systematic error/noise, which is the result of distortion the optical wavefronts transmitted or reflected by such devices. This can be compensated by means of a holographic correction element 24, used as

indicated in Figures 2a and 2b which depict a part of the correlator of Figure 1 modified to include such an element. This arrangement is suited to the operation of the spatial light modulators 11 and 12 as phase image generating devices i.e. the spatial field information is impressed on the phase of the interrogating beam of light from the laser 10 rather than upon its amplitude.

Figure 2a depicts the arrangement employed to create the required pattern of the correction element 24. A collimated beam of light from the laser 10 (not shown in this Figure) is incident normally upon the spatial light modulators 11 and 12 after transmission through the beam splitter 20. (For this purpose the laser 10 and its beam expander 19 is required to be temporarily shifted from the position shown in Figure 1 to the position occupied in that Figure by the lens 13.) Light which is reflected by the spatial light modulators 11 and 12, and is reflected by the beam splitter 20 is incident normally upon the undeveloped correction element 24. Here it is arranged to interfere with light from the laser that was first reflected by the beam splitter 20, and was then reflected by a plane mirror 25 before being transmitted through the beam splitter 20. The plane mirror 25 is tilted at a small angle 'a' so that the two beams interfere. The resulting interference pattern is recorded in the correction element 24 while no data is applied to either spatial light modulator 11 or 12.

The arrangement is changed to that of Figure 2b when the interference pattern recorded in the correction element has been fixed in the form of a phase object. The mirror 25 has been removed, the correction element is in its original position, and all the other components of the correlator are arranged as depicted in Figure 1. There is one exception to this, namely the laser 10 and beam expander 19 have been repositioned so that the expanded beam is incident upon the correction element at the angle 'a'. This is so that the light incident upon

the element emerges as a diffracted beam which is incident normally upon the spatial light modulators after reflection by the beam splitter 20.

5 It is only the diffracted beam which applied the wavefront correction, and hence it is desirable to minimise the amplitude of the undiffracted light. For this purpose the reflectivity of the mirror should match that of the spatial light modulators. In this context it may also be noted that bleached silver-based photographic
10 emulsions have been found to provide a diffraction efficiency which is surpassed by other types of photosensitive emulsions, such as the dichromated gelatin emulsion, and hence it may be preferred to use one of these non-silver-based emulsions where such use is not
15 precluded by virtue of wavelength sensitivity considerations.

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CLAIMS :

1. A joint transform correlator having first and second spatial light modulators for forming adjacent first and second coherent light phase or contrast images
5 in the input or object plane of the correlator, a dynamic hologram recorder spaced from the object plane, and an intervening first lens or lens system located such that the dynamic hologram recorder lies in the Fourier transform plane of the coherent light images, a coherent
10 light source for illuminating the dynamic hologram recorder, a two-dimensional image receiving photoelectronic transducer, and an intervening second lens or lens system located such that the transducer lies in the Fourier transform plane of the dynamic hologram
15 recorder, characterised in that the second of the spatial light modulators is adapted to be electronically controlled using a servo-feedback system to change its image to maximise the sharpness of the correlation image formed on the transducer.
- 20 2. An optical correlator as claimed in claim 1, wherein a holographic correction element is included in the optical path to compensate for extraneous wavefront distortion introduced by the spatial light modulators.
- 25 3. An optical correlator as claimed in claim 1 or 2, wherein the servo-feedback system includes electronic processing means responsive not only to correlation peak amplitude but also to shape.

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Fig. 1.

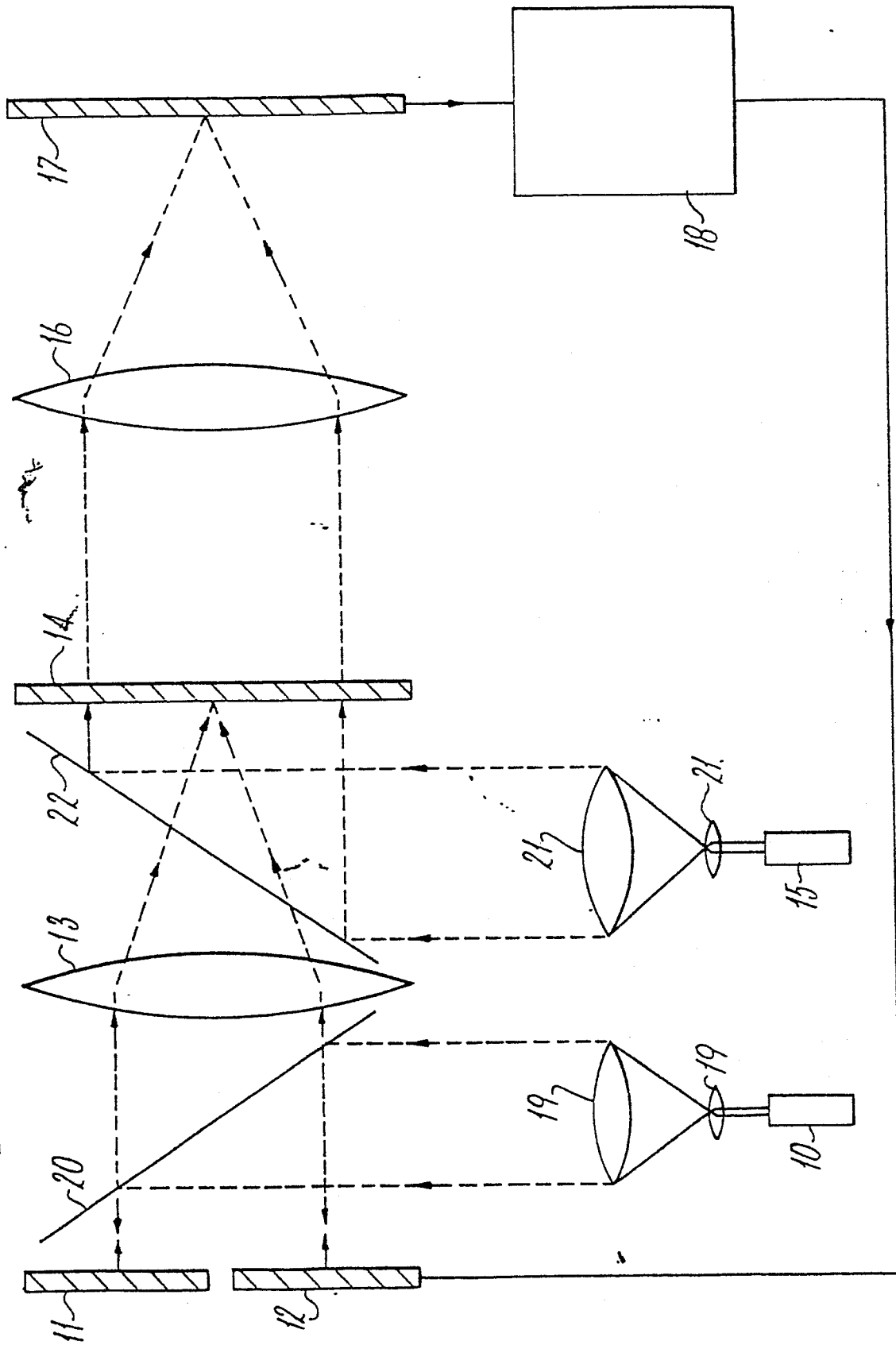


Fig. 2a.

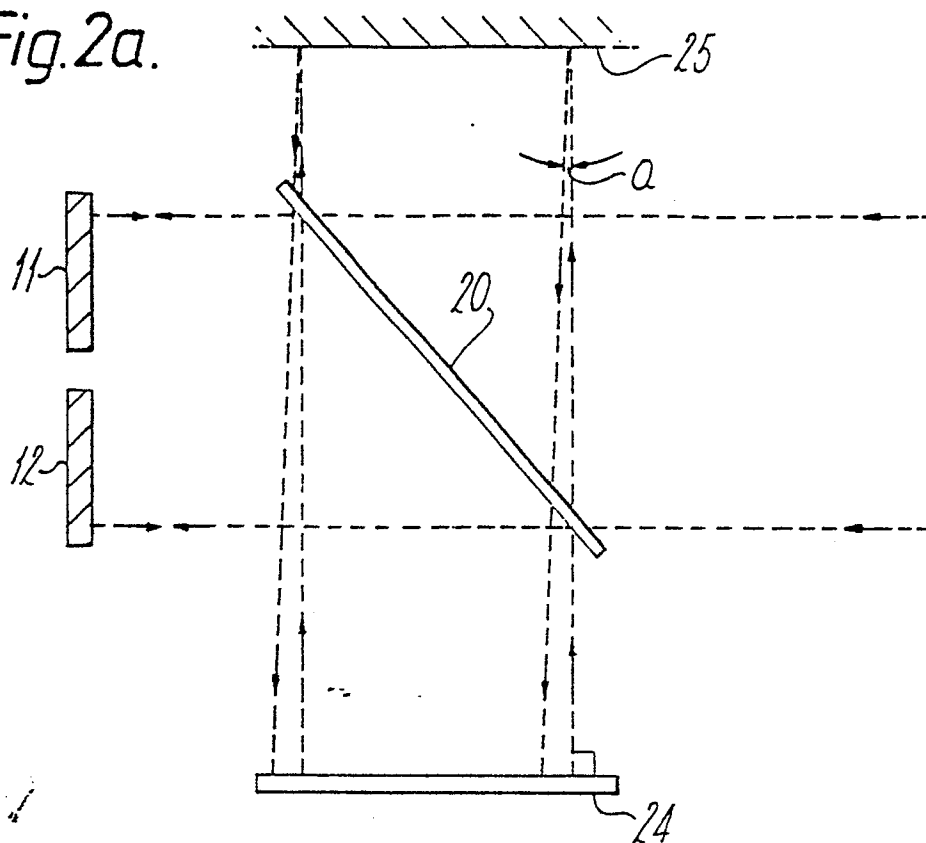


Fig. 2b.

