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Signal Processing Using Laser Speckle Technique

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ABSTRACT

Laser speckles has been widely used as a carrier of information. Speckle pattern resulting from the interference of random scattered coherent light from an optically rough object, has been used by many authors as a medium that can code different information. Image multiplexing using a laser speckle photography technique is capable of taking two or more exposures on the same holographic plate, with translation of the plate between exposures. In this paper an extraction of three multiplexed signals using random diffuser as a carrier is presented. Interference fringes obtained displaying each signal. The detection of the difference between two images has been applied using the same technique, in the recording step for two-signal multiplexing, the double exposure speckle photography technique has been applied for each signal a certain displacement between exposures. Two sets of interference fringes can be obtained, each displays the information of each signal. While in the filtering step the minimum fringes were allowed to pass and the difference between the two signals can be detected instead of using the maximum fringe pattern.

KEY WORDS

Optical Image Processing
Holography

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1- Introduction:

Several techniques have been suggested for image multiplexing in holography as well as ordinary photography [1]. The methods of multiplex image storage are based on modulating the signal with certain spatial carrier. Leith and Upatnieks[2] used different spatial carriers for different types of signals. Collier and Pennington[3] and Caulfield[4] have recorded different signals on different areas of the hologram, avoiding any overlapping.

In the theta modulation suggested by Armitage and Lohmann[5] a single carrier frequency was employed; this requires no interlacing of image elements and the carrier angles are independent of the image irradiances. The high rotational and wavelength sensitivity, consequently, the possibility of critical alignment of the hologram between the read-out beams, make the recording medium capable of storing a multiplicity of images, each produced with a differently oriented readout beam [6,7]. Another technique, which makes use of the entire area of the photographic plate to record the hologram of each of the signals to be multiplexed, which uses a single carrier frequency, has been proposed by Som and Lessard[8, 9].

In the present technique, a random diffuser is used to modulate the signal, recorded twice on the same photographic plate with a small displacement between the exposures. In the retrieval process, the Fourier transform of the signal is modulated by a system of [$\cos^2$] fringes. In this technique, as in Mueller's technique [6], several overlapped signals are recorded on a single frame, using the entire area of the photographic plate for each signal. The linear frequency storage capability of the film plays an important role in the success of this method. We shall describe the use of carrier frequency photographic technique using a random diffuser to provide a technique for multiplex image storage. Experimental results will be given to support the theoretical argument, followed by a brief discussion of the quality of retrieved images. The photographic emulsion imposes a further restriction on the total number of signals. The major drawbacks of this technique and the limitations imposed by the mechanical adjustment will be pointed out [9].

The light distribution, identical in all respects but displaced slightly relative to each other, gives a system of Young's fringes in the Fourier plane [10].

The interfringe spacing and the orientation of fringes depend, respectively, on the amount and the direction of lateral displacement of the two light distributions. Let an opaque screen, with a small slit, be placed in the Fourier plane with the slit coinciding with one of the fringe maxima. This passes the information carried by the fringe system. If the slit is displaced so that it coincides with a fringe minimum, no information will be transmitted. When there are two systems of fringes with different spatial frequencies, there will be points where some of the maxima of one system will coincide with some of the minima of the other. In other words, in the Fourier plane, there will be points that contain information from only one of the systems. If the slit is centered at such points, information carried by that system would pass whereas that due to the other will stop.

We record the given signals on the holographic plate by exposing it with two identical coherent light beams, and translating it through ζ_o in its own plane, perpendicular to the optical axis. After development processes, such holographic plate produces a system of linear fringes in the focal plane of the used lens, when it placed in front of coherent light source "Laser".

Consequently, two signals can be multiplexed in a single frame, and two dissimilar pairs of fringes could be originating from this frame. A diffuser modulates the signal in order to get a well-spread-out field for the system of Young's fringes. This form is the basis of the proposed technique for image multiplexing.

2- Two Image Multiplexing Using Random Diffuser:

The recording geometry is shown in figure (1), where a coherent beam of light illuminates a transparency 'T'. A Lens 'L' forms its image at T`. 'H' is a holographic plate placed immediately behind a diffuser 'D', to record the image. The holographic plate is mounted on a 3-dimensional translator, which could provide two perpendicular motions, parallel and perpendicular to the optical axis of the imaging system.

Micrometer screws control the motions in order to produce precise movements, with accurate values of displacements. The movement along the optical axis, which is perpendicular to the plane of the holographic plate, is used to adjust the distance between the plate and the diffuser, to be very small. In the retrieval system of figure (2), a slit is aligned with the fringes in the focal plane 'F'of lens L'. It is mounted on a carriage to give the ability for displacing it in a direction perpendicular to the fringes,

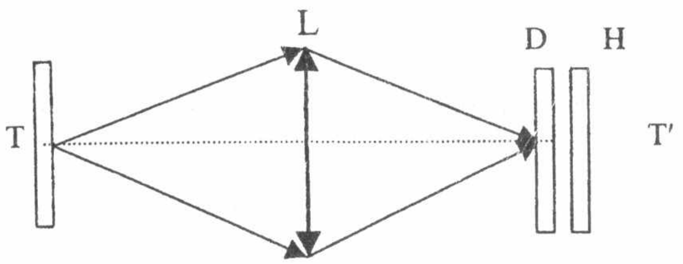


Figure (1) Optical arrangement for recording multiple images.

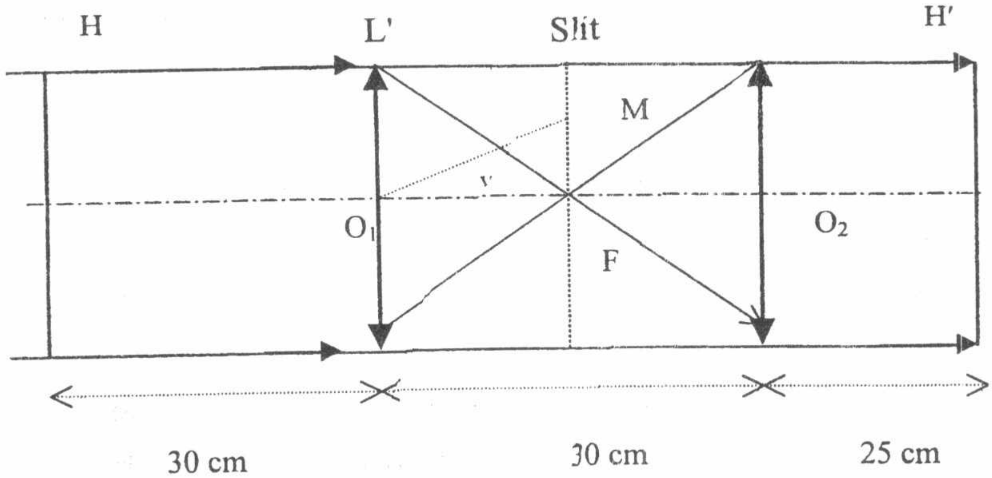


Figure (2) Optical arrangement for signal retrieval

2.1 - Theory of Double-Exposures:

Let G (η, ζ) represents the irradiance distribution in the image T , figure (1) and let D (η, ζ) be the transmittance of the diffuser. At any arbitrary point on the holographic plate the irradiance received is the product G $(\eta, \zeta) \times$ D (η, ζ). Let the holographic plate be translated with a small displacement ζ_o in its own plane and perpendicular to the optical axis of the imaging system. In this case, the irradiance at the same point will be

$$G(\eta,\zeta-\zeta_o) \times D(\eta,\zeta-\zeta_o) \tag{1}$$

If the holographic plate is given two successive exposures under the above –

mentioned condition, the total exposure recorded is

$$E(\eta, \zeta) = [G(\eta, \zeta) \times D(\eta, \zeta)] + [G(\eta, \zeta-\zeta_o) \times D(\eta, \zeta-\zeta_o)] \quad (2)$$

The plate, after development under the usual conditions of linearity, is mounted in the optical processor shown in figure (2), which is illuminated by a collimated laser beam. The amplitude transmitted by the plate is

$$t_n = t_o - \beta_o \{[G(\eta, \zeta) \times D(\eta, \zeta)] + [G(\eta, \zeta-\zeta_o) \times D(\eta, \zeta-\zeta_o)]\} \quad (3)$$

Where t_o and β_o are constant. At a point (υ, ν) in the focal plane F of the lens L`, the amplitude distribution is given

$$U(\upsilon, \nu) = FT[t_o] - \beta_o \{FT[G(\eta, \zeta) \times D(\eta, \zeta)] + FT[G(\eta, \zeta-\zeta_o) \times D(\eta, \zeta-\zeta_o)]\} \quad (4)$$

Where FT denotes the Fourier transform. Equation (4) can be simplified as

$$U(\upsilon, \nu) = FT[t_o] - \beta_o [1 + \exp(jk\nu\zeta_o)] \times \{FT[G(\eta, \zeta)] \otimes FT[D(\eta, \zeta)]\}, \quad (5)$$

Where $\otimes$ is the operation for convolution, and $k = 2\pi/\lambda$. The first term on the right-hand side of equation (5) represents the direct image of the source that is located at the focus of the lens L′. This is quite small and occupies a negligible field. In the second term, the factor $[1+\exp(jk\nu\zeta_o)]$, which corresponds to system of Young's fringes in the focal plane F. These fringes are perpendicular to the direction of translation. In figure(3) $\cos^2 k\nu\zeta_o/2$ is proportional to the irradiance of the fringes, and also to the real part of the amplitude. Now, if ζ_o is small, the fringes are quite broad; consequently, the adjacent maximum and minimum are well separated.

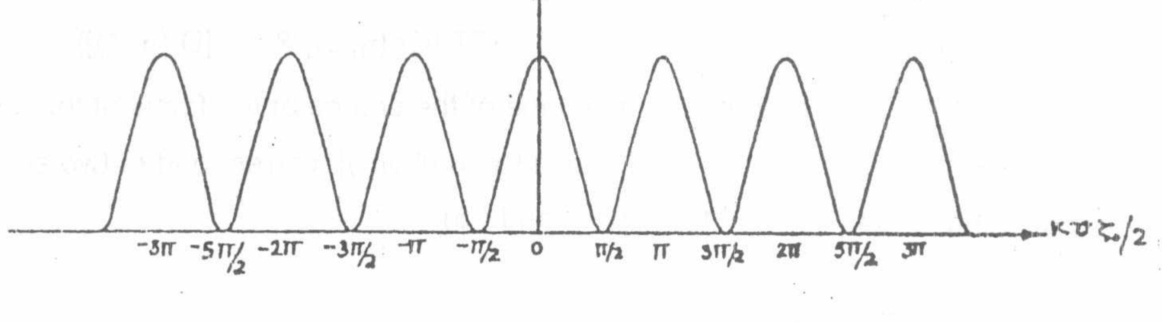


Figure (3) Fringe system due to signal recorded twice with a small displacement ζ_o between the exposures.

If an opaque screen, with a small aperture is placed in the focal plane F, such that the aperture lies on one of the maxima, the first term on the right-hand side of equation (5) is stopped, whereas the factor $[1+\exp(jk\nu\zeta_o)]$ becomes constant. Thus, on the other side of the aperture, only $FT[G(\eta,\zeta)] \otimes FT[D(\eta,\zeta))]$ multiplied by a constant is transmitted. One more, Fourier transformation restores the required distribution $[G(\eta,\zeta)] \times D(\eta,\zeta)]$.

It is obvious that, instead of an opaque screen with a single aperture, an array of slits can be used. These slits can be made to coincide with the maxima of the fringe system. When we translate these slits half a period, the transmittance is neglected. A convenient expression for the slit system can be obtained by convolution of a rectangular function with a Dirac-comb of suitable frequency.

Let two signals with irradiance distributions $G_1(\eta,\zeta)$ and $G_2(\eta,\zeta)$, independent of each other, be recorded on the same photographic plate, one after the other. For each signal two exposures are made with translations ζ_o and η_o, respectively, between the exposures. The total exposure recorded is

$$E'(\eta,\zeta) = [G_1(\eta,\zeta) \times D(\eta,\zeta)] + [G_1(\eta,\zeta-\zeta_o) \times D(\eta,\zeta-\zeta_o)] + [G_2(\eta,\zeta) \times D(\eta,\zeta)] + [G_2(\eta-\eta_o,\zeta) \times D(\eta-\eta_o,\zeta)] \tag{6}$$

After development, the amplitude transmittance is

$$t'_n = t'_o - \beta'_o \{[G_1(\eta,\zeta) \times D(\eta,\zeta)] + [G_1(\eta,\zeta-\zeta_o) \times D(\eta,\zeta-\zeta_o)] + [G_2(\eta,\zeta) \times D(\eta,\zeta)] + [G_2(\eta-\eta_o,\zeta) \times D(\eta-\eta_o,\zeta)] \tag{7}$$

Where t_o` and $\beta_o$` are constants.

In the focal plane F, the amplitude distribution is given by

$$U'(\upsilon,\nu) = FT[t_o`] - \beta_o`[1+\exp(jk\nu\zeta_o)] \times \{FT[G_1(\eta,\zeta)] \otimes FT[D(\eta,\zeta)]\} - \beta_o`[1+\exp(jk\nu\eta_o)] \times \{FT[G_2(\eta,\zeta)] \otimes FT[D(\eta,\zeta)]\} \tag{8}$$

Again, the first term represents the image of the source at the focus of the lens. The modulation factors $[1+\exp(jk\nu\zeta_o)]$ and $[1+\exp(jk\nu\eta_o)]$ correspond to two systems of Young's fringes, as shown in figures (4) and (5).

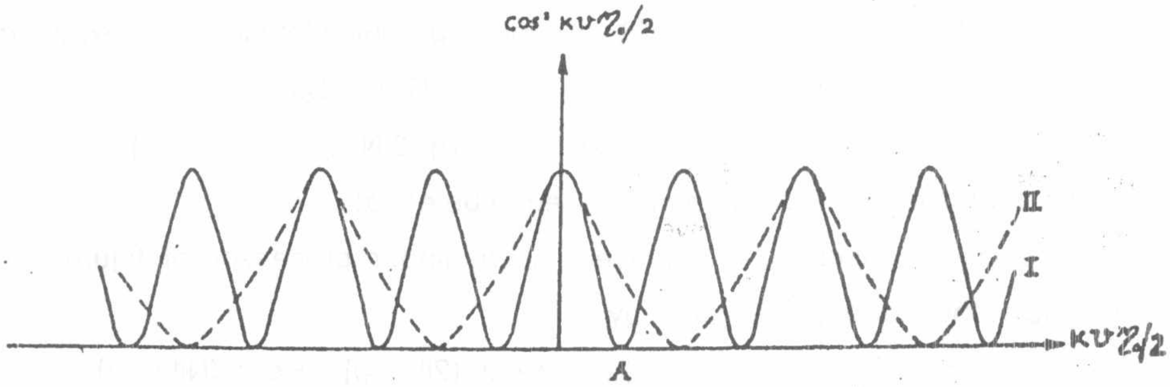


Fig (4)

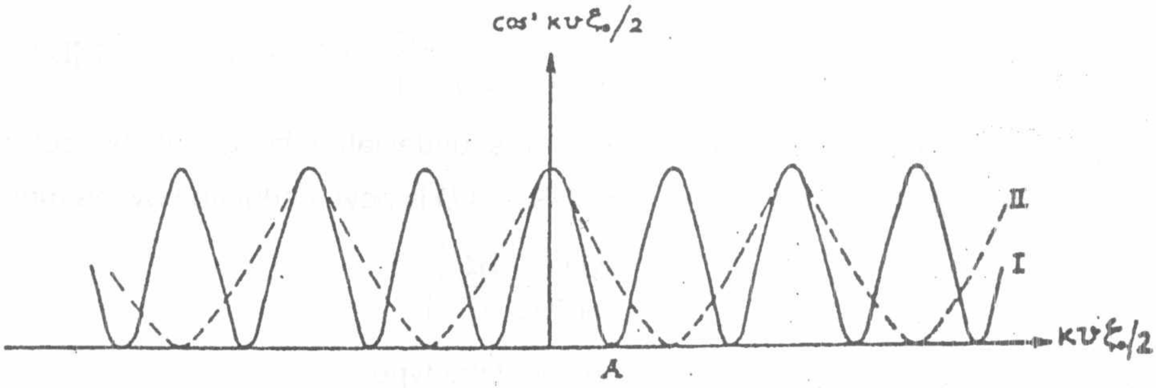


Fig (5)

Figures (4) and (5) Fringe systems due to two independent signals recorded with displacement η_o and ζ_o between the exposures of the two signals.

2.2- Multiple Exposures Technique:

In order to store a large number of images, it is necessary to decrease the width of the bright fringes. This can easily be done, by generating a system of multiple-beam fringes of the type given by a series of linearly arranged pinholes. The holographic plate can be multiply exposed to a given irradiance distribution, with small equal displacements of the plate between exposures. The finesse of the resulting fringes produced depends on the number of exposures. Such a system of fringes has been described by Burch and Tokaraski[11] and is identical to those obtained in multiple-beam hologram interferometry[12]. Continuing to use the same notations, we can write the total exposure received by the photographic plate in (N+1) exposures,

$$E(\eta,\zeta) = [G(\eta,\zeta)\times D(\eta,\zeta)] + [G(\eta,\zeta-\zeta_o)\times D(\eta,\zeta-\zeta_o)] + [G(\eta,\zeta-2\zeta_o)\times D(\eta,\zeta-2\zeta_o)]\ldots + [G(\eta,\zeta-N\zeta_o)\times D(\eta,\zeta-N\zeta_o)] \tag{9}$$

All of the N translations have been assumed to be equal.

The plate is developed and is placed in the linear processor of figure (2). The amplitude at the plane of L′ is given by

$$U(\upsilon,\nu) = FT[t_o] - \beta_o[1+\exp(jk\nu\zeta_o)+\exp(2jk\nu\zeta_o)]\ldots+\exp(Njk\nu\zeta_o)] \times FT[G(\eta,\zeta)]\otimes FT[D(\eta,\zeta)]\} \tag{10}$$

Which simplifies to

$$U(\upsilon,\nu) = FT[t_o] - \beta_o\left\{\frac{1-\exp[Jk\nu(N+1)\zeta_o]}{1-\exp(Jk\nu\zeta_o)}\right\}\times FT[G(\eta,\zeta)]\otimes FT[D(\eta,\zeta)] \tag{11}$$

Again, the first term corresponds to the undeviated image of the source. The convolution of the Fourier transforms of G and D is now modulated by the function

$$\left\{\frac{1-\exp[Jk\nu(N+1)\zeta_o]}{1-\exp(Jk\nu\zeta_o)}\right\} \tag{12}$$

Which corresponds to a system of fringes of the type

$$\frac{\sin^2[k\nu(N+1)\zeta_o/2]}{\sin^2(k\nu\zeta_o/2)} \tag{13}$$

Such fringes are obtained from a system of (N+1) equidistant pinholes of equal transmittance. Two main maxima are separated by (N-1) equally spaced secondary maxima, the irradinances of which can be taken, for all practical purposes to be zero if N is large enough.

In the presence of two dissimilar signals recorded on the same frame, equation(11) will be

$$U'(\upsilon,\nu) = FT[t'_o] - \beta'_o[\left\{\frac{1-\exp[Jk\nu(N_1+1)\zeta_1]}{1-\exp(Jk\nu\zeta_1)}\right\}\times\{FT[G_1(\eta,\zeta)]\otimes FT[D(\eta,\zeta)]\} + \left\{\frac{1-\exp[Jk\nu(N_2+1)\zeta_2]}{1-\exp(Jk\nu\zeta_2)}\right\}\times\{FT[G_2(\eta,\zeta)]\otimes FT[D(\eta,\zeta)]\} \tag{14}$$

Where N_1, N_2 and ζ_1, ζ_2 are, respectively, the numbers of exposures, and the displacements corresponding to the two systems of fringes. Proper selection of ζ_1 and

ζ_2 displaces the two systems of fringes relative to each other. The sharpness of the fringes makes possible the accommodation of a large number of images without any cross talk.

3- Experimental Technique and Results

3.1-Coding:

The recording system of two image multiplexing is shown in figures (6-a,b). A transparency object 'A' composed of "Tennis racquet", used as the image to be stored is shown in figure (7). A collimated beam of [10 mW] He-Ne laser illuminates the transparency object 'A', A lens O_2 of focal length 15 cm is used to form the image of A at plane H. The photographic plate of type "Agfa Gevart Holotest 8E75 HD NAH" is placed immediately behind the diffuser and approximately lie in the same plane. Now, light is allowed to pass through the object and propagates through the optical system to be encoded by the described artificial screen "diffuser" aligned parallel to ζ- direction, The photographic plate is mounted on a 3-dimensional micrometer stage, allows a 3-dimensional accurate translation of the film. The photographic plate receives now a double exposure of equal time and energy. The plate is displaced by an amount of 20 μm between exposures along the ζ-axis, this means that the image of the transparency 'A' is modulated now by a two shifted identical speckle pattern.

Applying the same procedure along the η-axis, the image of the second transparency 'B', which is "Muumental cups", is modulated by a two shifted identical speckle pattern.

The photographic plate is then processed under the normal conditions of linearity and then placed in the filtering system shown in figure (5-b). Now, we have two systems of interference fringes, perpendicular to each other, each represents one of the two coded images figures (7) and (8).

3.2- Decoding:

 # The retrieval images can be obtained by two techniques:

The first technique: the same set-up was used where we get the first image when the first fringe system maximum was allowed to pass, using the mask used in the single signal coding, for the same displacement. Rotating the mask by 90°, we find that the fringe maxima of the second fringe system is now coincide with the slits array used before and the second coded image will be obtained. This is shown in figures (9- a, b).

The second technique is new: In this case, minimum fringes corresponding to one signal was allowed to pass, by using filter or mask with very narrow slits, and make these slits coincides with fringe minima. Accordingly, small parts of maximum fringes of the other signal will pass; in which it carried information about this signal. Such his signal was imaged with a quartz lens of focal length f = 15 cm, to be retrieved from these two- multiplexed information. We found that, this retrieved signal has no information about the other signal. These information was recorded on the photographic plate, which was processed by using D-19 Kodack developer for (3-minute), and it was dipped into water, and kept it in fixer for (15-minute), shown in figures (10- a, b).

Subtraction of two signals: By using the set-up shown in figure (6-a,b). The first transparency object used is the slide of letter "A", was placed in the recording plane, figure (11-a), and a first exposure is taken for 20 sec. Another slide replaced the first one representing the letter "A enclosed a frame" , figure (11-b), and a second exposure is to be taken for the same exposure time, on the same photographic plate after a displacement of ζ_o=20μm along ζ-axis for the film. This photographic plate is processed under the normal conditions.

This plate is placed in front of a collimated laser beam, and by using a quartz lens of focal length (f = 15 cm), interference pattern of Younge's fringes is observed in the Foruier-plane as shown figure (12). This experiment was repeated by changing these two objects with each other, and minimum fringes was allowed to pass, to retrieve the difference between these two- multiplexed signals as shown in figures (13-a,b).

Another technique, can be used for detecting the difference between two signals, but with multiple-exposure; first exposure for the transparency slide "A in its frame" with exposure time 10 sec, the second slide to be subtracted from the first one was "A", second exposure was taken to this slide with exposure time equals (5 sec), but with small displacement ($+\zeta_o$ = 10 μm) along ζ-axis, and third exposure are recorded in the opposite direction ($-\zeta_o = 10\ \mu m$), for the same time (5 sec), this plate is placed in front of a collimated laser beam, and by using a quartz lens of focal length (f= 15 cm), interference pattern of Younge's fringes is observed in the Foruier-plane.

By allowing the minimum fringes only to pass, the difference between these signals can be detected and recorded on the photographic plate, after developing for 4 minute with D-19 Kodak developer, This is printed as shown in figures (14- a, b), and looks more precisely than the first method.

4- Conclusion:

In this work coding of information has been experimentally presented using speckle technique. Single image has been coded using speckle photography technique which leads to the formation of interference fringes of ($\cos^2$) type.

For the case of single image storage, one system of interference fringes is obtained using the double-exposure technique. In the retrieval step a mask allows the fringe maxima to pass the signal can be extracted. To get a less noisy retrieved image the fringe system should be very sharp and this can be done using multiple-exposure speckle photography technique, where the fringe contrast is increased.

For the two image storage two interference fringe systems are obtained, these systems are perpendicular to each other using the same mask, one can get each of the two images alone by orienting the mask 90°. It is clear that high contrast fringes can be obtained using a multiple-exposure technique.

For the subtraction of two images they are allowed to be recorded on the same plate. However, the first exposure with one image while the second contains the two images overlapped. Between the exposures the photographic plate was displaced by a distance of (20 μm). The plate after processing under normal conditions is placed in the set up of figure (5) where bright and dark fringes were observed. A mask of the same spatial frequency as the fringe pattern was used to extract the difference between the two images by allowing the fringe minimum to pass through the grid (mask).

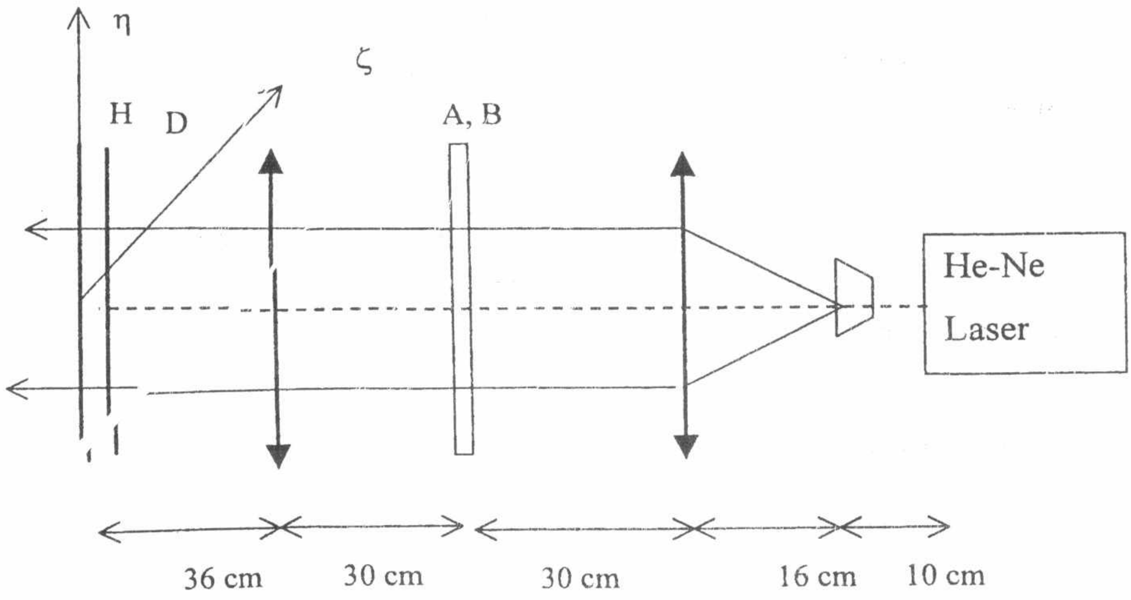


Figure (6-a) Arrangement used for multiplexing of two images

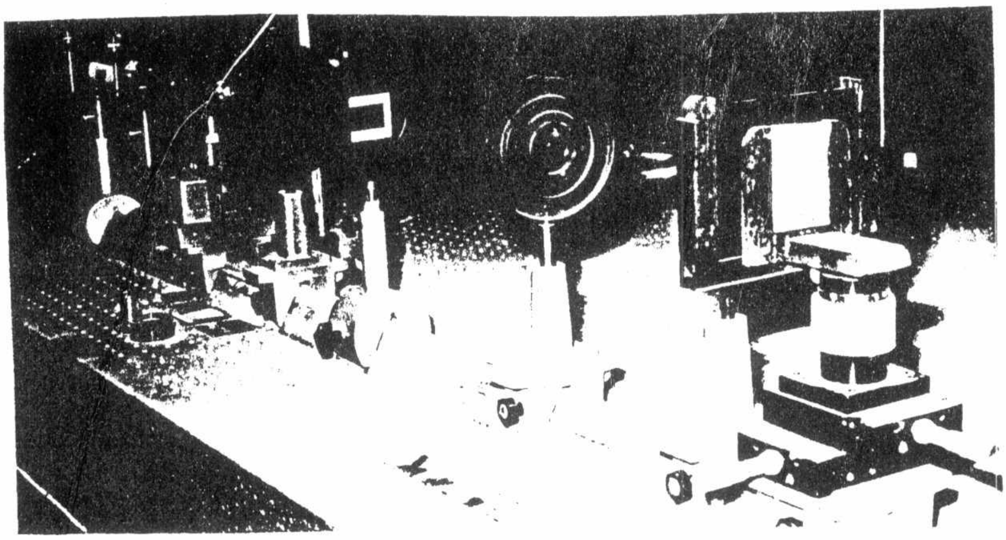


Figure (6-b) Photograph for the recording set-up

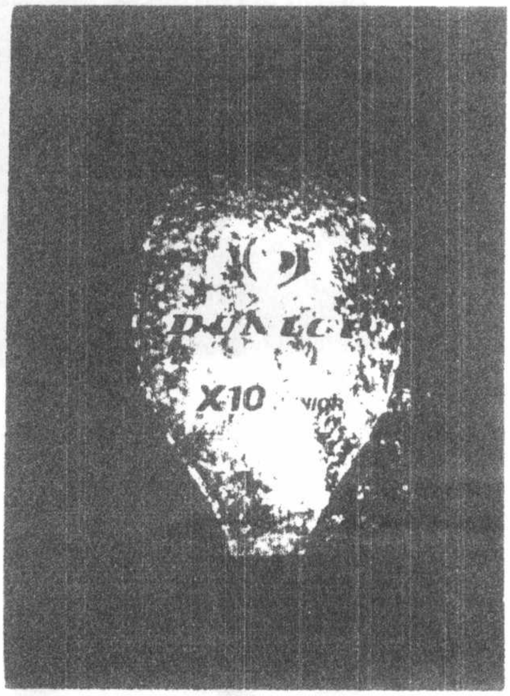


Figure (7) The recorded two-image signals

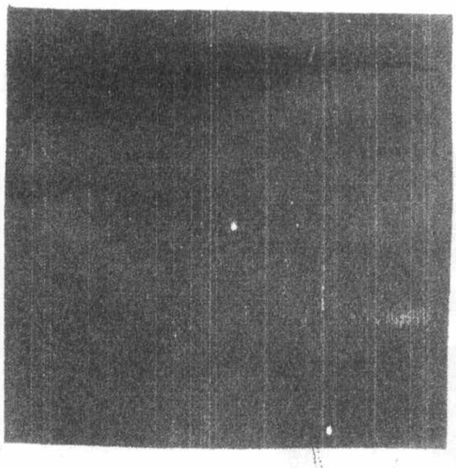


Figure (8) Diffraction pattern modulated by Young's fringes

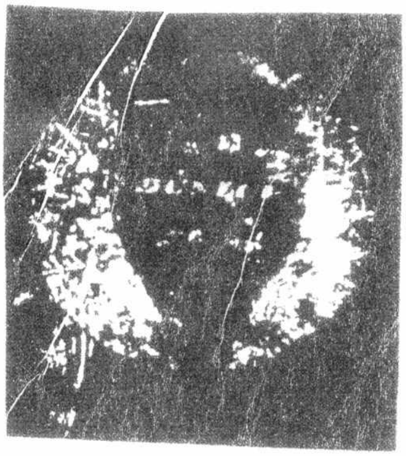


Figure (9-a) Retrieved signal of "Tennis racquet" by passing Six fringe maxima

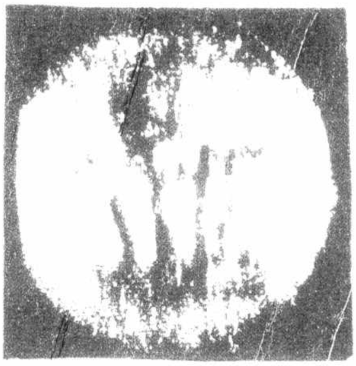
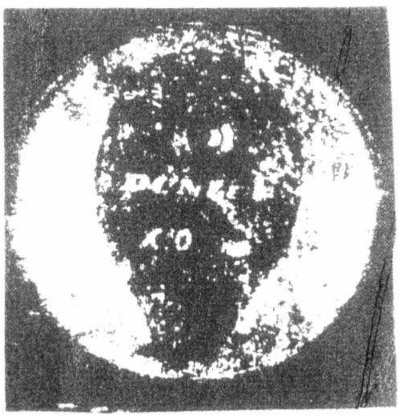


Figure (9-b) Retrieved second signal by passing two fringe maxima



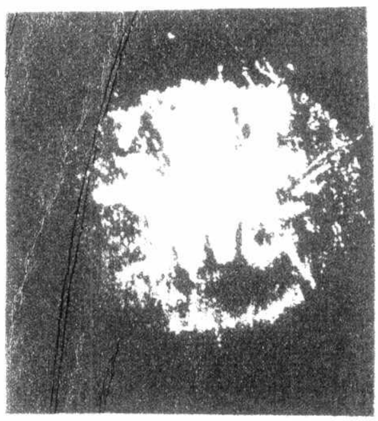


Figure (10-a, b) Retrieved signals by passing six fringe minima of the second signal and two fringe minima of the first signal

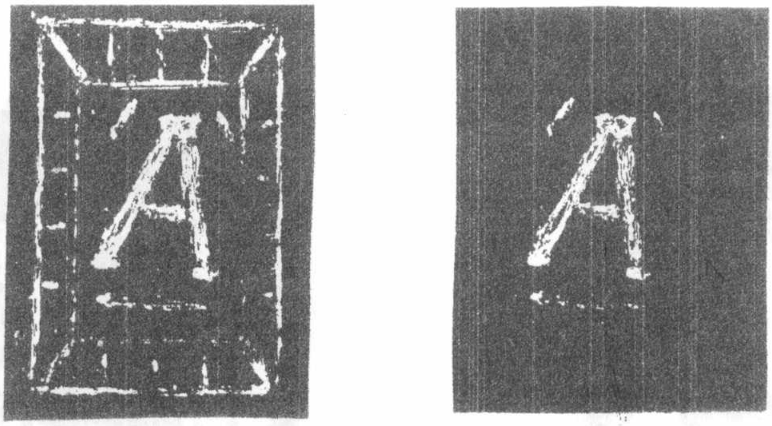


Figure (11-a,b) The transparencies used for subtraction between two signals

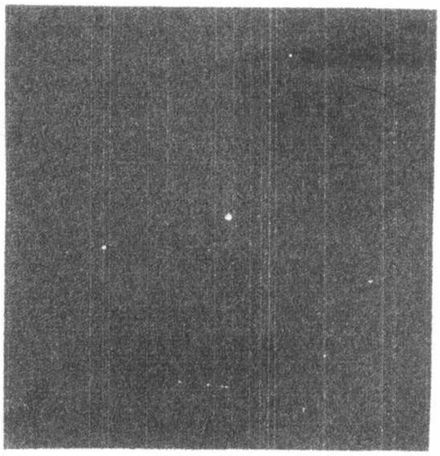


Figure (12) Diffraction pattern modulated by Young's fringe

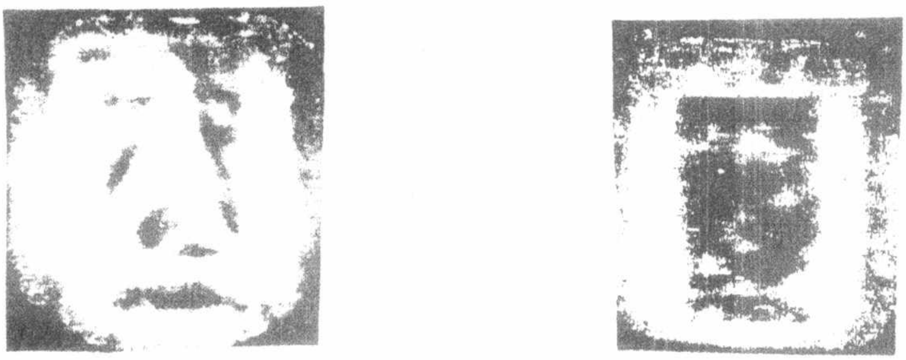
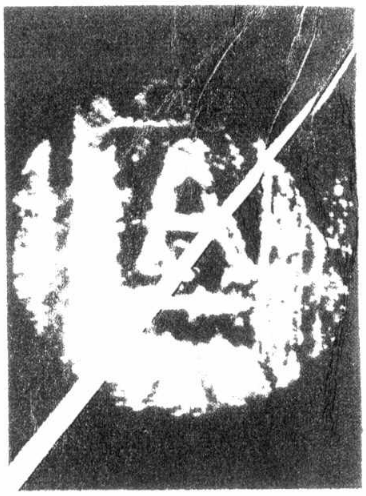


Figure (13-a, b) Retrieved images from double- exposure technique



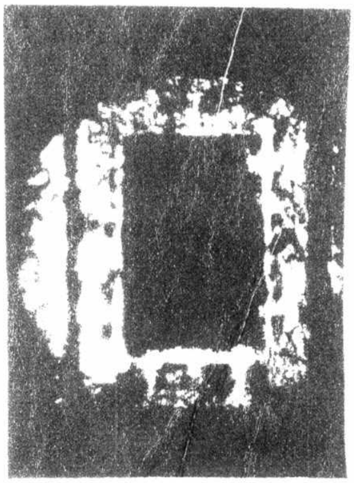


Figure (14-a, b) Retrieved signals from multiple- exposure technique

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