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INFORMATION CONTENT AS A PARAMETER OF ACOUSTICAL HOLOGRAM RECONSTRUCTIBILITY

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The aim of this paper is to discuss the information content of an acoustical hologram and to determine its dependence on the determining parameters. It is also to look for the threshold of the information content which has to be reached in order to perform a successful reconstruction of the hologram.

Introduction

Information content is one of the parameters which characterises every information system. The holographic visualisation method may be considered as a method which permits the storage of a large amount of information. The rigorous determination of the information content of a hologram is a complicated problem which has not yet been fully solved. This paper presents a preliminary attempt to quantify the information content of acoustical holograms.

Theory

Let the coordinate plane x, y be identical with that of the hologram. Then the information content of the hologram, I_0 in the first approximation is determined as [1]

$$I_0 = \log_2(H_x H_y / l_x l_y) \quad [\text{bit}], \tag{1}$$

where l_x and l_y are the minimum resolvable distances along the x and y axes, respectively; H_x and H_y are the dimensions of the rectangular hologram. To assess the information content of the acoustical hologram I_a we shall start from this formula.

During visualisation with acoustical holography the problem of sampling the hologram at discrete points often arises. It is necessary to determine the number of these points for which the amplitude has to be sampled in order to optimise the recording of the information on the subject coded in the interference pattern. The sampling theorem [2] determines the number of these sampling points. Under the theorem, an arbitrary wave front across the aperture S, containing spatial frequency variation up to a limit of B lines/cm is recorded fully if its amplitude is sampled at intervals of $1/2\ B$ cm. This means that for a rectangular aperture of area $S = H_x H_y\ \mathrm{cm}^2$ the wave front is fully determined by sampling at $4B^2S$ points. In this way the information about the subject coded in an acoustical hologram can be recorded most effectively. Further increase in the number of points recorded does not contribute to increasing the information content. This means that the points in which the information, for the determination of the information content of an acoustical hologram should be sampled, are spaced by $1/2\ B$ cm. Thus the information content of the hologram is

$$I_a = \log_2 4B^2 S. \tag{2}$$

If the smallest spacing of lines d (d^{-1} is the spatial frequency of the interference pattern) is $d = \lambda/2\sin\theta\sin\Phi$ [2], where λ is ultrasonic wavelength, 2θ

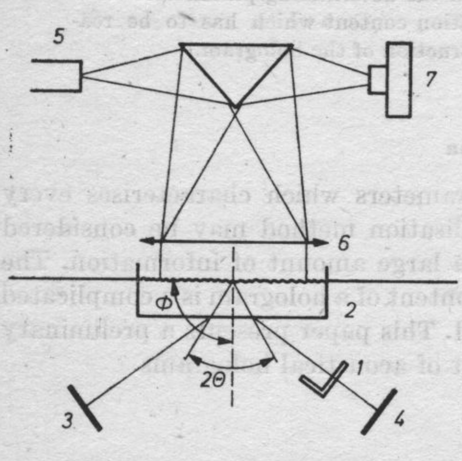


Fig. 1. Experimental set-up
1 – object, *2* – minitank, *3* and *4* – reference and object beams, respectively, *5* – He-Ne laser with optical system, *6* – lens, *7* – camera

is the angle between the reference and object beams, Φ is the angle between the line bisecting the angle 2θ and the hologram plane (see Fig. 1) then the information content of an acoustical hologram is given by

$$I_a = \log_2(16S\sin^2\theta\sin^2\Phi/\lambda^2) \tag{3}$$

or

$$I_a = \log_2(16Sf^2\sin^2\theta\sin^2\Phi/c^2) \quad [\mathrm{bit}], \tag{4}$$

where c is the velocity of the ultrasonic wave and f its frequency. It is easy to see that I_a is a function of five independent parameters. Figs. 2-4 shows I_a as a function of some of these parameters. It can be seen from Fig. 2 that in order to increase the information content of the hologram, increasing the area is more effective than increasing the frequency. The influence of the value of the ultrasonic velocity on the information content of the hologram is shown in Fig. 3. It can be seen from this curve that it is necessary, when choosing the liquid in the minitank, to consider not only its surface tension and viscosity but also its

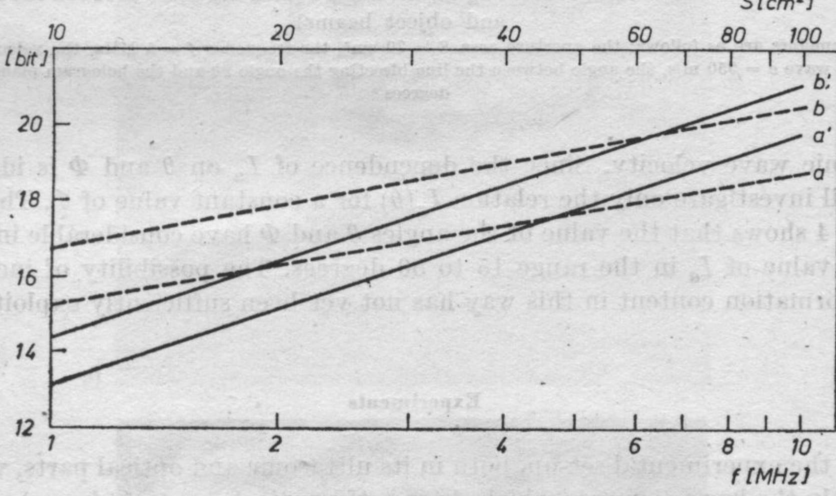


Fig. 2. Curves of the information content I_a vs. the aperture area S

a – for 3 MHz; b – for 5 MHz. Other parameters are as follows: the angle between the reference and object beams, $2\theta = 60$ degrees; the angle between the line bisecting the angle 2θ and the hologram plane, $\Phi = 90$ degrees; the velocity of the ultrasonic wave $c = 950$ m/s. Curves of I_a vs. the frequency f : a' – for S equal to 20 cm², b' – for S equal to 50 cm². Other parameters are as follows: $c = 950$ m/s, $2\theta = 60$ degrees, $\Phi = 90$ degrees

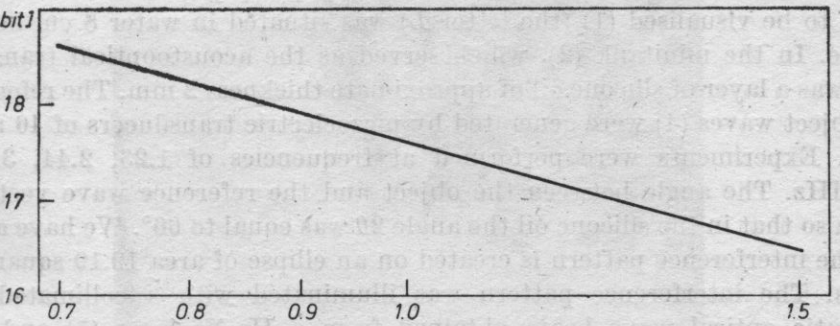


Fig. 3. Curve of the information content I_a vs. the velocity of the ultrasonic wave c

other parameters are as follows: the aperture area $S = 20$ cm², the frequency $f = 5$ MHz, the angle between the reference and object beams, $2\theta = 60$ degrees; the angle between the line bisecting the angle 2θ and the holograme plane $\Phi = 90$ degrees

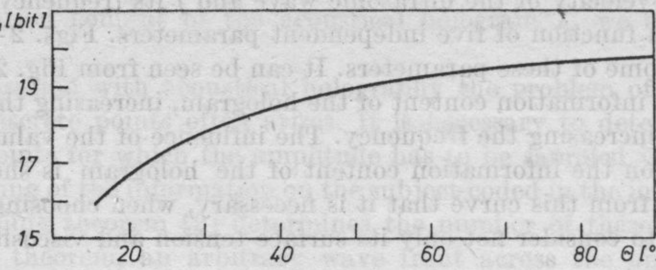


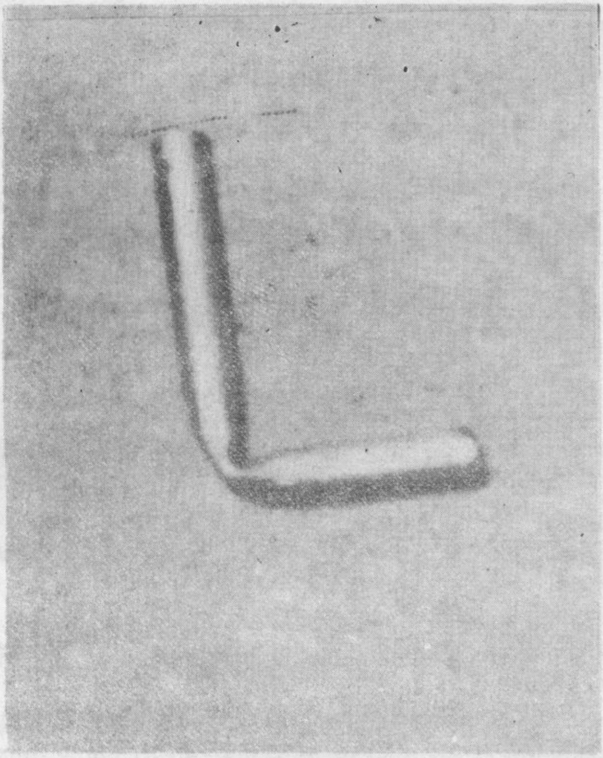
Fig. 4. Curve of the information content I_a vs. the angle θ (half the angle between the reference and object beams)

other parameters are as follows: the aperture area $S = 20$ cm², the frequency $f = 5$ MHz, the velocity of the ultrasonic wave $c = 950$ m/s, the angle between the line bisecting the angle 2θ and the hologram plane, $\Phi = 90$ degrees

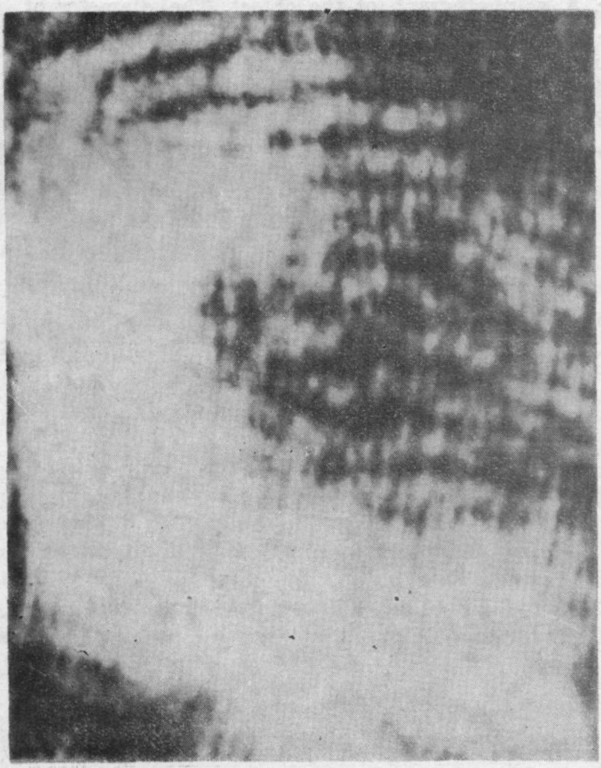
ultrasonic wave velocity. Since the dependence of I_a on θ and Φ is identical, we shall investigate only the relation $I_a(\theta)$ for a constant value of Φ. The curve in Fig. 4 shows that the value of the angles θ and Φ have considerable influence on the value of I_a in the range 15 to 50 degrees. The possibility of increasing the information content in this way has not yet been sufficiently exploited.

Experiments

In the experimental set-up, both in its ultrasonic and optical parts, we have used only the basic elements which, from a theoretical point of view, are needed for holographic imaging. We have used no such elements or methods as acoustical lenses etc. which would decrease the intrinsic noise of the experimental apparatus and influence the amount of artifacts. The experimental acoustical holography set-up using free liquid surface deformation as the acoustooptical transformer, which is similar to that described in another paper [3], is shown in Fig. 1. The object to be visualised (1) (the letter L) was situated in water 8 cm below the surface. In the minitank (2), which served as the acoustooptical transformer, there was a layer of silicone oil of approximate thickness 2 mm. The reference (3) and object waves (4) were generated by piezoelectric transducers of 46 mm diameter. Experiments were performed at frequencies of 1.23, 2.44, 3.62 and 4.88 MHz. The angle between the object and the reference wave vectors was chosen so that in the silicone oil the angle 2θ was equal to 60°. We have assumed that the interference pattern is created on an ellipse of area 19.19 square centimeters. The interference pattern was illuminated with a collimated monochromatic optical wave beam obtained from a He-Ne laser (5) and optical system. Since the spatial frequency d^{-1} influences the separation of the diffraction orders [4], the record of the created interference pattern – the hologram – was reduced optically by a factor of aproximately four and recorded on a photographic plate (7). The reconstruction was thus not carried out in real time.



a)



b)

c)

Fig. 5. a) photograph of the object. The diameter of the tube is 0.3 cm, the height is 2.0 cm; b) the reconstructed image at a frequency of 2.44 MHz; c) the image at a frequency of 4.88 MHz

Discussion

Values of the calculated information content of the acoustical holograms recorded on the elliptical area mentioned above for the described experimental conditions are presented in Table 1. The reconstruction of the object recorded

Table 1

f [MHz]	1.23	2.44	3.62	4.88
I_a [bit]	13.66	15.63	16.80	17.75

in the hologram at the lowest frequency of 1.23 MHz was not possible as a result of the strong influence of the noise of the experimental set-up and artifacts. The images of the same object obtained by reconstruction of the holograms recorded at frequencies of 2.44 and 4.88 MHz are shown in Fig. 5b and 5c along with the photo of the object itself (Fig. 5a). The improvement of the quality of the image of the object with the increasing I_a of the hologram is distinct. It is reasonable to assume that it should, in the near future, be possible to determine the quality of the reconstructed image by means of the parameter of the information content I_a, using some objective physical method.

On the basis of the preliminary results obtained we suppose that in order to obtain an image when reconstructing an acoustical hologram it is necessary to make a hologram having information content of about 15 bits. Since the quality of the image increases with increasing information content, it is necessary to reach as high a value of I_a as is possible. In acoustical holography visualization by means of a free liquid surface, it is necessary to take into account the aim of the visualization (nondestructive testing, medical diagnostics, etc.), and the dependencies plotted in Figs. 2-4. One should decide on the basis of an analysis of the purpose of the visualization process the physical parameters by means of which this goal could be achieved.

The results presented here are considered to be preliminary one. A more exact formula for I_a as well as objective criteria for the reconstructibility of acoustical holograms should be developed in the near future.

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