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HOLOGRAPHY IN MOTION PICTURES AND TELEVISION*

B. P. KONSTANTINOV

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I do not propose to report anything sensational concerning the use of holography in motion pictures and in television. I want to express certain opinions on holographic motion picture and television, on the possibility of their realization, and to discuss the following questions. First, what is to be meant under holographic motion pictures and television? Second, what advantages does the use of various holographic methods in motion picture and television offer? Third, what are the technical prospects of the application of holographic methods in motion pictures and in television?

In the opening lecture of our school, S. M. Rytov said that the three-dimensional appearance of images in stereoscopes, in stereo motion pictures, and in stereo television is essentially an optical illusion. However, this optical illusion, which produces the sensation of three dimensionality and is due to the fact that humans have two eyes with a distance 60–65 mm between them, shows that not much is needed to produce the impression of three-dimensionality. The absence of parallax in stereo motion pictures and in stereo television should not greatly influence the sensation of three-dimensionality, since the viewer seated in front of the stereo television screen or in the motion picture theater cannot jump from place to place as if possessed in order to see the parallax in the image. At the same time, the fullness of the perception is greatly increased in motion picture photography. The effects of three-dimensional perception appear in wide-screen motion pictures without any stereoscopic devices. They are attained in this case as a result of the screen dimensions and the use of wide-angle optical systems. These effects produce not only a stereoscopic impression, but even give the viewer the feeling as if he were taking part in the action on the screen. The viewer feels himself to be among the performers. Those who have seen the Italian-French motion picture "Grand Prix" recall the sensation of participation in the races, although there is no stereoscopy at all. The three-dimensionality sensation in wide-screen motion picture is attained, in addition, as a result of the fact that the objects move and change their positions all the time. However, no three-dimensional sensation is produced at large distances to the image, owing to the smallness of the base distance between the eyes. It is interesting that the three-dimensional perception of flat objects, including motion picture and television images, can occur when a flat image is viewed with one eye. If a good photograph or a motion picture screen is viewed with one eye, then a three-dimensional sensation is still obtained, even through there is no binocular vision in this case. A distinct illusion of three-dimensionality is produced, and disappears immediately as soon as the second eye is opened. The vanishing of this illusion is due to the fact that the second eye destroys the "deception," and establishes the two-dimensionality of the image. It should be stated that the produced illusion of three-dimensionality of a two-dimensional image makes a great impression. The three-dimensionality sensation is connected here with the sizes of the objects and with the perspective reproduced by the photographic camera.

If the recording material has a sufficient resolution, a hologram can be produced in such a way, that when the image of an object or a group of objects is reconstructed, it can be viewed from all sides, including from above and below, i.e., the image reconstructed from a hologram is indeed three-dimensional. A hologram has a large dynamic range of brightnesses, unattainable in a photographic plate or a television screen. In addition, an image from a hologram having only two graduations, black and white can have a large number of half-tones. As shown in his lecture by Professor A. L. Mikaélyan, the actual reconstruction of the image can be reviewed with a magnifying glass or with the aid of a microscope, by focusing on different planes of the object. Whereas at the beginning of the century, Boltzmann's constant was determined by counting spherical particles of gamboge suspended in a liquid under a microscope, we could now obtain with the aid of a pulsed laser a hologram of a volume of a cell with particles suspended in it, and then investigate the distribution of the particles by viewing the actual reconstruction of the image. In the lecture of B. G. Turukhano, who dealt with problems of determining the spatial distribution of particle tracks in a bubble chamber, it is indicated that it is possible to process the holographic images a posteriori. In this case it is possible to analyze not only the equilibrium distribution of the particles in an emulsion or a suspension, but also the establishment of the equilibrium, the size distribution functions, etc. Such a use of holography offers researchers great possibilities.

Leith, Upatnieks, and others have discussed the question of the use of holography in motion pictures and in television. They reached the conclusion that in order to realize holographic television it is necessary to employ very large bandwidths corresponding to that tremendous amount of information that should be recorded in the hologram. Indeed, if we count the information transmitted per second in the course of color television transmission, assuming that the frames appear at a frequency of 25 Hz, and the number of resolution elements is on the order of 400,000 at 10 tone gradations and 3 colors, then the amount of information turns out to be tremendous. In color motion-picture photography, the bandwidth also reaches tens or hundreds of MHz. However, color motion picture films are

*Lecture delivered on 24 January 1969 to the participants of the School of Physical Principles of Holography (20–25 January 1969, Moscow). This was the last public appearance of Academicina B. P. Konstantinov, who died on 9 July 1969.

much easier to produce than television transmission, inasmuch as the information is transmitted over many channels. In motion-picture photography there is no need for space scanning of the image, i.e., of converting the spatial distribution of the brightnesses into a time sequence of signals. It is clear that for the transmission of a colored three-dimensional object an even larger bandwidth is required than in color television or in color motion-picture photography. It is possible that the carrier frequency in holographic three-dimensional television would lie in the infrared or in the visible band.

Let us determine what is to be defined as holographic motion pictures and television. Let us stop first to discuss television. What must be done to realize three-dimensional holographic television, i.e., to observe utimately the virtual reconstructed image? It is perfectly clear that it is necessary to produce a screen on which it is possible to display holograms reconstructed with the aid of a local source of light. The screen dimensions must be large enough to permit the viewer to observe parallax when he changes position. Only then will the three-dimensional perception be complete. However, the realization of such a system encounters a number of difficulties. The first of them is the production of the screen on which to produce holograms. Photographic materials are not suitable for the construction of such screens. To be sure, recalling the history of the development of television, there existed a German "swishing film" system in which the image on the receiving end of the television system was recorded on motion-picture film. The film was processed and fed into a motion picture projector. Naturally, this involved a certain time delay. However, the delay is irrelevant, since we view television programs in recorded form quite frequently. At the present time, tape recording is used for this purpose. Systems similar to the "swishing film" system date back to the thirties are not in use now. One could use a similar system for large-screen television in special institutions or halls, but it is not convenient for general use. In addition, projection on a large screen does not solve the problem, since we must produce on the large screen not an image, but a hologram. How is a hologram to be produced on a large screen? We could use, for example, some photochromic material, which changes its transmission under the influence of, say, an electron beam. Then, using a sufficiently powerful laser light source we could reconstruct the three-dimensional image, and the problem would be solved. The use of photochromic materials for the registration of holograms is presently under study.

I wish to emphasize that to transmit a sufficiently large amount of information, which would make it possible to view a three-dimensional object with large resolution, it would be necessary to have a screen on which holograms are produced by bypassing the photographic process, so that the reconstruction of the image would be realized with the least time delay or without any delay relative to the instant of formation of the hologram. Thus, to obtain television transmission, at least 90% of the hologram must vanish within 1/25 sec. In addition, screens on which holograms are produced should have a high resolution. The use of photochromic materials may be one of the ways of realizing holographic television. Another way is to use a system which, in principle, makes it possible to obtain a hologram on a liquid film. We have in mind the large-screen television system known as Eudophor. In this system, an electron beam scans a film of vacuum oil deposited on a concave mirror. The beam scans the image in the same way as in ordinary television receiving tubes. The electron beam, as stated by the inventors of this system, deposits a charge on the surface of the film, and since the metallic surface of the film is grounded, the motion of the charges under the influence of the electrostatic forces leads to the formation of a relief on the oil film. Thus, a variable-density liquid film is produced on the mirror, corresponding to the television-image frame. Further, the liquid with the relief produced on it is used to modulate a light flux from a powerful source, the modulation being of the multichannel type in this case. The phase variations are converted into amplitude variations by the Toepler method, and it is possible to see a normal television image on a large screen. The production of such devices has already been started in our country. For holographic television, there is no need to use the Toepler shadow method. It suffices to illuminate with laser light a hologram produced on a liquid film by an electron beam, and this makes it possible to observe a three-dimensional image in reflected light. It is possible that such systems will serve as the basis for the development of holographic television.

Thus, were we to succeed in creating suitable transmitting devices, (vidicons, orthicons, or superorthicons) having enough resolution elements for holography, and were it possible to use a sufficiently broad frequency channel, on the order of several dozen or hundred MHz, then by using on the receiving end a device of the "Eudophor" type or a screen made of photochromic material, it would be possible to realize three-dimensional holographic television.

Let us turn now to holographic motion picture photography. To realize holographic motion pictures we need to produce a hologram on the entire screen, whether it be of the wide-screen or of the panoramic type, and then reconstruct the image. By what means? So far, we can think of only two. The first is a screen of photochromic material and the second is the use of laser illumination to reconstruct holograms. Only if the hologram is produced on the screen itself can we speak of holographic motion picture photography proper. This technique is at present exceedingly complicated. In television the situation is somewhat easier. There the problem is mainly connected with the need for using a very broad frequency band. In holographic motion picture photography, on the other hand, this is the problem of producing a holographic material with an area on the order of hundreds of square meters.

In addition, for holographic motion pictures, as for holographic television, we are faced with the problem of producing the holograms. This raises the question already mentioned by Mikaélyan. This is the question of the coherence length. It is perfectly clear that it is impossible to photograph a hologram for some battle scene, but this is not necessary, since the three-dimensional perception vanishes at large distances. Shortrange photography also raises complicated problems, and Professor Mikaélyan states that one method of solving them is to use delayed reference beams. It is apparently possible to conceive of something more effective for this purpose than Fabry-Perot etalons, say interferometers. In any case, the problem still remains. If we start thinking about obtaining holograms of large objects or of objects located at large distances, it seems that they can be obtained more easily by using not the optical band, but longer wavelengths, say millimeter waves, and perhaps even centimeter waves. This raises the question of whether an image similar to the object can be produced in this case. It is known that we obtain the sensation of an image as a result of reflection of the light incident on the object—red, yellow, or blue. The reflection coefficients of the surface of the object at different wavelengths can be different, and this produces the color sensation. But how will the face of a brunette appear to us in the five millimeter band? It is possible that the hair will remain black, owing to the large absorption of radiation as a result of dispersion, and the face will remain white, but different inversions may arise and the image may be very unattractive. Let me remind you that an ultraviolet microscope was developed at one time in our country at the Optical Institute. The human eye does not perceive ultraviolet radiation. How could one characterize the color of the object? Professor E. M. Brumberg has shown that this can be done purely arbitrarily. We choose two or three wavelengths in the ultraviolet region of the spectrum and assign to each of them a definite color in the visible region. We can then observe in ultraviolet rays objects having an arbitrary color. In visible light, the objects can be perfectly identical, but in the ultraviolet they can be different, and we can therefore recognize them and by the same token obtain additional information, say concerning the structure of cells or microorganisms. In this sense, research can be organized aimed at preparing holograms at millimeter or submillimeter wavelengths, and to assign definite colors to them. It is probable that this will require a definite choice, and possibly also the use of special makeup for the performers, as is now already done in television studios. It is possible that photography of holograms, just as in ultraviolet microscopy, will be carried out at radio frequencies, and the reconstruction will be effected in the visible region of the spectrum, but with a suitable choice of wavelength ratios.

The following definition can be proposed for true holographic television or motion pictures: True holographic television and motion-picture photography is holography on large surfaces and the reconstruction of holograms directly from the screen of the television apparatus or from the motion picture screen. Thus, those working on the creation of holographic motion pictures or television are faced with exceedingly complicated problems. For television, this is mainly the problem of using very broad frequency bands, and for motion pictures it is the problem of the principles and construction of the holographic screen.

It is possible, however, to use holographic methods in motion pictures and in television not quite in the sense referred until now. It is known that in the case of image transmission in television, the spatial distribution of the illumination of some screen is converted by scanning into a time sequence of signals. The scanning is linewise and framewise. We choose a certain number of lines, for example 625 lines in this country, a smaller or a larger number in other countries, making it possible to transmit the image with a definite sharpness, as verified by test tables. In the twenties, Professor Termen of the Leningrad Physicotechnical Institute was working on television, and since he wanted to develop a television system rapidly, he had to use a mechanical scanning system. The total number of transmitted elements amounted to only several hundred, whereas now the number of elements amounts to hundreds of thousands. Although the number of elements was small, the objects which he transmitted could be easily recognized. Thus, depending on the requirements imposed, it is sometimes necessary to transmit a large amount of information, and sometimes a small amount. It is appropriate to raise here the following question: how can holographic methods be helpful in the solution of specific problems? Let us assume that we wish to transmit the same amount of information as can be carried by the existing television system. Is it advantageous to use holographic methods in this case or not? I shall attempt to answer this question.

If a certain image is produced on the screen, then the illumination of the screen is a function of two variables. Such a function, at least in some cases, can be analyzed naturally with the aid of double Fourier series. As a result of an analysis we obtain a set of amplitudes for the different harmonics as functions of two coordinates. Will such an expansion make it possible to get along with a smaller amount of information than in the case of direct transmission of the image? If high frequencies were not transmitted in this case, then the sharp boundaries between the dark and light parts of the image would be lost after the inverse transformation. Physiological investigations of the properties of vision have shown that relatively slow changes of the brightness of the screen are transformed by the eye into rapid ones, i.e., less distinct transitions between black and white are converted by the eye into more distinct ones. This property of vision makes it possible, as it were, to obtain the same result at the output when a smaller amount of information is transmitted, and consequently at a smaller bandwidth. In the late thirties, papers were published, in which a method was described for realizing Fourier expansion and synthesis of one-dimensional objects with the aid of masks. However, the method of masks cannot be employed in technology, since the resultant systems are very cumbersome, expensive, and difficult to produce. On the other hand, if we turn to holography, then we obtain precisely the direct and inverse Fourier transformations. If a certain object, say a transparency, is reproduced by holography, then, depending on the angle at which the reference beam is incident on the recording medium, we obtain some conversion of the frequency. For example, we can eliminate completely the low spatial frequencies. The low frequencies in the usual television system are needed because they are responsible for the transmission of slow changes of the illumination over the entire screen, whereas for the hologram the low frequencies are of no importance at all, and can be eliminated completely, i.e., we transfer the frequency region to some other level and use a narrow frequency band. A similar transmission of information can be of interest because the space-frequency characteristics of the receiving screens may depend, and in fact do depend, on the spatial frequency. The idea of such a transmission has been in existence for a long time, but no one has ever realized it, since there were no technical means for realizing the indicated transformation. Holography, on the other hand, allows us to do so. Thus, there exists a region of application of holography in information transmission, in which it is convenient to carry out the conversion of the spatial frequency.

Another useful property of the holographic method is the possibility of using only two signal gradations. It is practically impossible to view a television image in the absence of halftones, but an image reconstructed from a hologram transmitted by only two steps will be a halftone image. A third property of the holographic method, which may be useful for the use of holography in television, is the large dynamic range.

Finally, there are cases when there is no need to have detailed information on the object, say when we deal with the recognition of objects. There are many problems in which it is necessary to recognize images by certain common attributes. In this case the use of the holographic procedure may turn out to be exceedingly useful, for example, in outer-space communication. In transmissions from outer space, from some space stations, the transmitter power may not be very large, and in addition, there are very strong attenuations and distortions of the signal. Therefore, to separate the signal from the noise background it becomes necessary to repeat the transmission many times. The holographic method turns out to be useful in this case because the hologram has the property that each of its points contains information on the entire object as a whole. For example, the transmission of photographs of craters on Mars or of the place of landing of space ship from an orbital station consumes much time, since it is necessary to transmit the entire frame of the image in order to obtain the necessary information. On the other hand, if one transmits not the image but the hologram of the photograph, then as the signals are received we obtain information concerning the entire object as a whole, and the sharpness of the reconstructed image will increase continuously. If we verify that the surface is not suitable for spaceship landing, we stop the transmission and the communication channel is free for the next transmission. It may turn out, on the other hand, that the transmitted information suffices, and more detailed information can be obtained later, when the communication channel is not needed for the transmission of more important information.

Thus, owing to the aforementioned properties, holographic methods may turn out to be useful and convenient in systems for the transmission of information.

A hologram of a transparency with the legend "Bell" on it was transmitted over a communication channel for the first time by Americans. In our country, similar work was done by Klimenko and Rukman. Simultaneous work was performed on the transmission of holograms over communication channels at the Leningrad Physicotechnical Institute, in the laboratory of S. B. Gurevich and in my laboratory.

If we wish to transmit a hologram containing the same amount of information as a frame of a television image or a facsimile blank, then, in view of the fact that holography employs conversion of spatial frequencies, namely, a shift to the region of higher frequencies, it is possible to use holograms with smaller dimensions. In this case it may be necessary to increase the hologram in order to permit the existing apparatus to transmit it. Further, after the transmission over the communication channel, it is possible to reconstruct the image without changing the scale of the hologram and thus obtain a reduced image, or else it is possible to obtain an image having the initial dimensions by changing the scale.

In practice, the transmission of a hologram over some communication channel is realized in the following manner. First the photo-hologram is obtained, after which a suitable section on it is chosen. This section is projected with magnification on a screen, say, of a vidicon, or on the blank of a facsimile system. Then usual transmission is effected. After reception of the image of the hologram, the scale is changed, and the image of the object is reconstructed.

Such operations were performed first within the confines of the institute, and then on the facsimile line between Leningrad and Moscow and Leningrad-Moscow-Leningrad. Under laboratory conditions, the holograms were transmitted in black and white through a closed television system and through a closed phototelegraph channel. In addition, the transmission was simulated by rephotographing the holograms on an electrographic copying apparatus in a regime close to a two-gradation regime. The following objects were transmitted: a chart used to determine the resolution of optical systems, a half-tone transparency, and a diffusely-scattering three-dimensional object.

The results have demonstrated the possibility of transmitting holograms at large distances over standard photo-telegraphy channels with reconstruction of the images of the foregoing objects on the receiving end. The possibility was established of using for the transmission of boolograms channels with a limited number of signal levels, and the consequences of the loss of information in these systems, leading to a deterioration of the quality of the reconstructed objects, were determined.

Thus, quite promising research in this direction is now under way, although it is clear that the practical application of the holographic method still meets with great difficulties. As to the creation of a true three-dimensional holographic motion picture system or television system, this problem is too difficult and probably, to obtain a sufficient stereoscopic sensation, it will be easier to produce binocular-type systems, which S. M. Rytov has characterized as "deceptive." An example of the possibility of creating systems that ensure a fully sufficient three-dimensional perception are the stereoscopic post cards, produced, say, in Japan, which can be viewed without any devices. On the post cards there are several photographs taken at different angles, and when a raster optical system is placed directly on the post card, it is possible for the observer to perceive clearly the three-dimensional character of the image.

Translated by J. G. Adashko