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On holographic information content and its compression

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Abstract

The present paper, based on the information theory of Shannon, studies the holographic information content, its reconstruction, and the compression of the hologram. Starting with the human binocular vision theory, it elaborates not only the information contents of the 3D object and its hologram, but also their relationship in the visual space. By proposing the particular computing method for the holographic information content and achieving meaningful results therefore, it offers the theoretical cornerstone and practical way to the reduction and compression of the holographic information content.

Keywords: Information content of the 3D object; Holographic information content; Digital hologram display

1. Introduction

An important technique for information recording and display, holography has been widely applied in many fields [1,2]. With more and more in-depth researches on digital holography and holographic TV and its telecommunication, increasing attention has been paid to the study concerning the information content of hologram [3,4]. However, up to now there has not a systematic theory about the information content of hologram. The study of the information content of digital hologram is very important for compression and simplification of hologram, and the holographic information compression rate is connected directly with the practice of holographic information transmission and display in real time. We have tried to investigate hologram compression by means of wavelet analysis and achieved some valuable results [5,6], but there are yet a lot of problems that need further discussion. The first is how to scientifically compute the information contents of 3D object and its hologram in theory, and the second is what the limit of holographic information compression rate is. The answers to the two questions involve not only the information contents of 3D object and its hologram, but also their relationship. In this paper, we attempt to study the limit of holographic information compression rate and its compression way based on the relation between the information content of recorded object and that of hologram, thereby offering the theoretical foundation and way for the holographic information compression.

2. The information content of 3D object

Okoshi made some preliminary study about the information content of hologram [7]. He figured out the maximal pixel number of the reconstructed image according to the size of hologram, but failed to deal with

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the relation between the information content of the hologram and that of the actual object, and the redundancy and compression of the hologram information. Based on the information theory, the information content I in the light field propagation can be expressed [8] as

$$I = N \log_2 (1 + m), \tag{1}$$

where N is the freedom degree of light field, including the freedom degrees of space, color, polarization and time, and m is the signal-to-noise of the light field. In the holographic display process, we only attend the freedom degree of space since the carrier wave of 3D information is often linearly polarized monochromatic light. Apparently, the effect from the freedom degree on the information content is larger than that from the signal-to-noise m due to the logarithmic relation in the Eq. (1). So the information content of the light field can be discussed around its freedom degree. It has been proved that the freedom degree in light field is actually the Shannon number, namely, it is bandwidth-product. On the other hand, the study of information content of 3D object cannot be divorced from the theory of man's binocular vision since the 3D object used for display is exactly the image in human eyes. The visual field of man's fixed eyes is normally affected by two factors, i.e., reading distance and visual angle. That is to say, the visual field in depth is from normal reading distance to infinitude and that in width is binocular visual angle as the shadow region shown in Fig. 1. However, how much is the information content of 3D object and how many image points can be seen by human eyes in the human binocular view space? The important difference of information content between 3D object and 2D object lies in that the former is decided not only by the structure and resolution of the object but also by its information of spatial situation.

Now we compute the number of object points in the binocular view space provided that there is a moving range for the two eyes. The number of object points in the binocular view space lies on the resolution of human eyes. Usually, we attend the object's resolution on one plane when we discuss the resolution of human eyes. In fact, because of the optical diffraction in the stereo display, the resolution in depth and in lateral should be taken into consideration simultaneously when we study the resolution of human eyes for object. Wolf proposed the concept of Airy ellipsoid corresponding to that of Airy disk, namely, the space area in which the image points can be resolved [9]. The volume of the space area reads

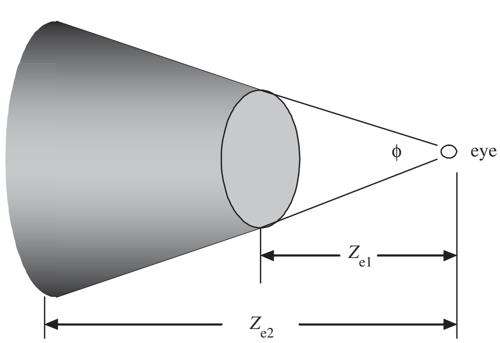

Fig. 1. Vision field of an eye.

$$\delta v = \frac{\pi}{2\cos^2 \varphi}\,\lambda^3 \left(\frac{z}{D}\right)^4, \tag{2}$$

where z is the distance from object point to pupil, D is the pupil diameter, λ is wavelength, and φ is the included angle between pupil normal and image point direction. From formula (2), we know that, though distributing continuously, the spatial objects are scattered into discrete ellipsoids as a result of the restrictions on the resolution of the image-forming system, which can discern neither the variety of brightness nor that of depth in each of these ellipsoids.

Now, we are interested in how many object points can be told apart in the visual field of a human eye. As shown in Fig. 1, we assume that the human visual angle is ϕ and the visual range is from distance Z_{e1} to distance Z_{e2}; then the number of image points in the shadow region that can be resolved, according to formula (2), is

$$N = \int_V \frac{d\tau}{\delta v} = \frac{D_e^4}{12\lambda^3}\left(1 - \cos^3 \frac{\phi}{2}\right)\frac{Z_{e2} - Z_{e1}}{Z_{e1} Z_{e2}}. \tag{3}$$

In formula (3), D_e denotes the pupil diameter. Considering the stereo effect of binocular vision, it is necessary to compute the number of the resolved image points in the human binocular visual area. Apparently, most of the image points seen by two eyes coincide, but for simplicity, we estimate roughly that the number of image points seen by two eyes is twice as many as that seen by one eye shown in formula (3). So the actual number of image points is less than the estimate value. Then, we discuss the information content of 3D object as follows:

(1) *The whole visual field in the still human eye case*: In this case, we assume that the letterZ_{e2} in formula (3) is infinite, the normal reading distance Z_{e1} is 250 mm, the visual angle ϕ is about 120°, the wavelength λ is 0.6 μm and the pupil diameter is 3 mm. So the number of image points is

$$N = \frac{D_e^4}{6\lambda^3}(1 - \cos^3 60^\circ)\frac{1}{Z_{e1}} = 2.1875 \times 10^8. \tag{4}$$

(2) *The whole visual field in the moving human eye case*: We know that a stronger stereoscopic perception can be acquired when the spatial object has an obscure effect resulting from the moving eye. When the eye is moving in the range of pupil distance, its visual field