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Binary hologram generation based on shape adaptive sampling

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ABSTRACT

Past research has revealed that by down-sampling the projected intensity profile of a source object scene with a regular sampling lattice, a binary Fresnel hologram can be generated swiftly to preserve favorable quality on its reconstructed image. However, this method also results in a prominent textural pattern which is conflicting to the geometrical profile of the object scene, leading to an unnatural visual perception. In this paper, we shall overcome this problem with a down-sampling process that is adaptive to the geometry of the object. Experimental results demonstrate that by applying our proposed method to generate a binary hologram, the reconstructed image is rendered with a texture which abides with the shape of the three-dimensional object(s).

1. Introduction

Ever since the pioneering work in the 1960s [1,2], investigation on the generation of binary digital holograms has become an area of interest. The pursuit of research along this direction is driven by two major factors. First, the data size of a binary hologram is considerably smaller than a gray-level hologram, as each pixel is a single bit representation. Second, a binary hologram can be printed with high resolution commodity printers [3], which in general can only produce black or white dots. This allows binary holograms to be printed swiftly and at low cost as compared with the expensive and the time-consuming fringe printer [4]. On the downside, a binary hologram is only containing partial information of its corresponding gray hologram, hence leading to distortion on the image it represents. A viable approach to lower the distortion can be realized by recursively modifying a binary hologram until the discrepancy between the original and the reconstructed image is minimized [5–7]. However, such process is time-consuming, and it is difficult, if not impossible to reconstruct a 3-D object scene with a wide depth range. Faster methods that employ error diffusion [8], have been reported in the binarization of Fourier [9–11] and Fresnel [12] holograms. Despite the swiftness and effectiveness of these methods, the optical reconstructed images of holograms binarized with error diffusion are weak and contaminated with noise. Recently, Tsang et al. [13] have proposed a fast, non-iterative method for generating binary Fresnel holograms. In the approach, the orthographic projected intensity image of a three-dimensional scene is first down-sampled with a uniform grid lattice. A digital Fresnel hologram is generated based on the down-sampled intensity image and its corresponding depth map. Subsequently, the hologram is binarized with sign thresholding, assigning black and white dots to negative and positive pixels, respectively. As illustrated in the article [13], as well as other variations on the method [14–16], a binary hologram generated in this manner is capable of preserving, to a good extent, the shaded regions of the object scene. Despite the success of this approach, the reconstructed image is masked with a prominent, regular texture that is often conflicting with the geometrical profile of the original scene, and results in an unnatural appearance. In this paper, we propose a method to overcome this problem. Briefly, given a 3-D object that is composing of a wire-frame model and a texture image, the latter is down-sampled with a uniform grid-cross lattice. Next, the wire-frame model is rendered with the down-sampled texture image. The intensity and depth of each object point on the rendered object that is visible from sight is taken to generate a Fresnel hologram. Subsequently, the Fresnel hologram is binarized with sign-thresholding. Organization of the paper is given as follows. In Section 2, a brief outline on the binary hologram method in [13] is described. Our proposed method is presented in Section 3. Experimental results showing the reconstructed images of binary holograms generated with our proposed method are given in Section 4. Finally, a conclusion summarizing the essential findings is given in Section 5.

2. Computer generation and binarization of Fresnel holograms

For the sake of completion, a brief outline on the binary hologram generation method reported in [13] is presented with the aid of Fig. 1, showing an arbitrary three-dimensional (3D) scene.

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Each object point in the scene is assumed to be self-illuminating. We denote the orthographic projected image of the 3D scene, and the distance of each point to the hologram, with the intensity profile function $I(u,v)$ and the depth map $D(u,v)$, respectively. The object wavefront $O(x,y)$ is derived by accumulating the optical wave emitted from the sampled points, as given by [1]

$$O(x,y)|_{\substack{0 \le x < X \\ 0 \le y < Y}} = \sum_{u=0}^{X-1}\sum_{v=0}^{Y-1} \frac{I(u,v)\exp(i2\pi r_{u;v;x;y}/\lambda)}{r_{u;v;x;y}}, \quad (1)$$

where λ is the wavelength of the optical beam. $r_{u;v;x;y} = \sqrt{(x-u)^2+(y-v)^2+D(u,v)^2}$ denotes the distance between a point located at (u,v) in the 3D scene, and a point (x,y) on the hologram. X and Y are the horizontal and vertical extents of the hologram, respectively, which are assumed to be identical to that of the image scene. Subsequently, the object wavefront is multiplied with a reference plane wave $R(y)$ that is inclined at an angle θ along the vertical direction. The real part of the product is extracted as an off-axis hologram $H(x,y)$ given by,

$$H(x,y) = RE[O(x,y)R(y)]. \quad (2)$$

In Eq. (2), discarding the imaginary part of the product will lead to a real hologram, but at the same time generating a de-focused twin image, which will overlap with the reconstructed image if the angle θ of the inclined plane wave is zero. As such, the value of θ must be large enough to steer the twin image away from the reconstructed image. $H(x,y)$ can be directly converted to a binary hologram with sign-thresholding, assigning black and white intensities to negative and positive hologram pixels. However, as explained and demonstrated in [13], if a binary hologram is generated in this straightforward manner, the shaded region in the reconstructed image will be severely weakened. To overcome this problem, the projected intensity image $I(u,v)$ is down-sampled with a uniform grid lattice into a sparse image, which is taken to generate a binary hologram. As shown in [13], the reconstructed image of the binary hologram of the down-sampled object scene is capable of preserving the shaded area in the reconstructed image, which otherwise will be lost if sign-thresholding is applied to a hologram that is directly generated from the original object scene (i.e., without down-sampling). In addition, negligible computation is involved in the down-sampling process, constituting to a major advantage of this method. On the downside, as we shall illustrate later, the down-sampling process will cast a strong, regular pattern on the reconstructed image which is often conflicting with the geometrical profile of the object, leading to an unnatural appearance.

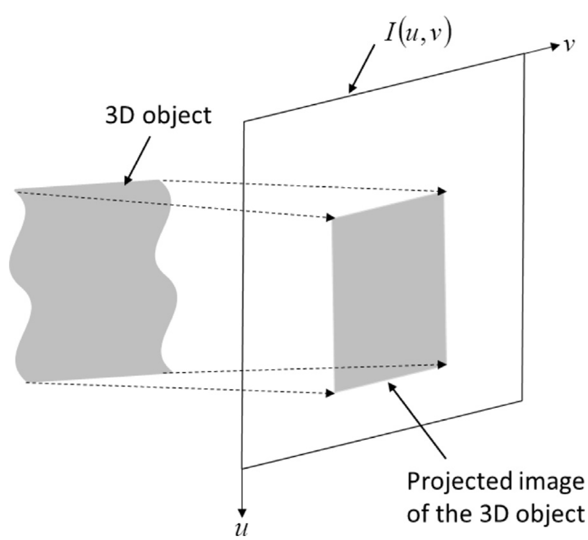

Fig. 1. Orthographic projection of a 3D object.

3. Proposed method for generating a binary hologram for representing a 3D model

To alleviate the unnatural appearance on the reconstructed image caused by the regular grid-cross sampling lattice, we propose a new scheme as depicted in Fig. 2.

Our proposed method can be divided into 4 stages, and outlined as follows. To begin with, we consider a 3D object composing of a set of object points, each defined by its intensity and Cartesian co-ordinates in the 3D space. In practice, a set of object points are generally represented with a computer graphic (CG) model comprising of a 3D polygon mesh P and a 2D texture image $T(u,v)$. The polygonal mesh is simply a logical grouping of triplets or quadruple of neighboring object points, in a way that the polygons are non-overlapping, but at the same time covering the entire surface of the object. An example of two polygons formed by six object points $\{o_0, \ldots o_5\}$ is shown in Fig. 3, where the two polygons are not on the same plane in general.

However, the vertices of the polygons (each being an object point) do not carry the intensity information. In addition, the surface of each polygon is empty and does not contain any object point. The texture image $T(u,v)$, is a "flattened" version of the intensity distribution of the object points into a 2D square or

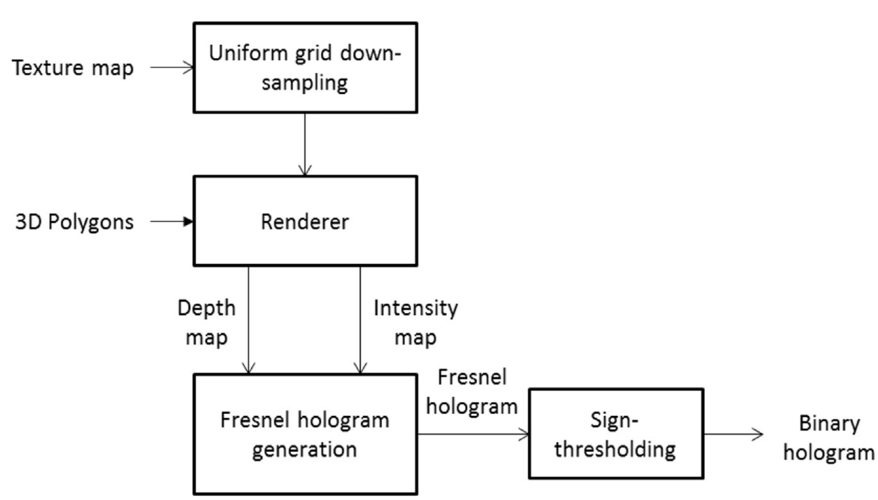

Fig. 2. Proposed method for generating a binary Fresnel hologram.