Research Article

Research on Hologram Based on Holographic Projection Technology

Yan Li, Qun Yu, Yu Wu, and Changcheng Wei

Department of Mathematics and Computer Science, Tongling University, Tongling, Anhui, China

Correspondence should be addressed to Changcheng Wei; changcheng@tlu.edu.cn

Received 10 February 2022; Accepted 23 March 2022; Published 20 May 2022

Academic Editor: Tabasam Rashid

Copyright © 2022 Yan Li et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In recent years, holographic projection technology has been integrated into the real society, which brings a new visual experience to people and meets their high requirements for audiovisual experience. With the development of holographic technology, the hologram from holographic technology has also attracted people’s attention. The application of holograms in the fields of art, science, and technology conforms to the trend of the times and will become an indispensable part of people’s life in the future. In this paper, it mainly studies the hologram to analyze its algorithm and production process and its application prospects.

1. Introduction

The holographic projection technology has developed rapidly in recent years, and its applications in the fields of entertainment, medicine, research, and commerce are endless, like visual studies, scientific visualization, virtual presentations, etc. [1, 2]. Holographic projection is a form of 3D technology developed by Dr Dennis Gabor of the Imperial College London to improve the resolution of scanning electron microscope [3].

The continuous development of holographic projection technology now provides us with increasingly accurate three-dimensional images known as holograms [4]. We can re-see the original recording of the three-dimensional image of the object, the hologram has become a judge of whether the 3D technology we are exposed to holographic projection technology standards. Today, computer-generated holography is a new technique for making holograms, which are synthesized using a digital computer, without the physical presence of an object; instead, the mathematical description of the object wave is input to the computer and processed to control the output of the plotter or display two made of holograms [5]. In addition, the optimization algorithm of phase-only holograms has been a research hotspot for a long time.

2. Concept of Hologram

Holograms, which are recorded on high-resolution holographic film by using a panoramic camera and a laser as light source [6], exist in the form of interference fringes. And if the same kind of laser is irradiated, two stereo images will appear on the front and back of the holographic film. That is, the two images of the original scene, real and virtual, have different images from different perspectives. Moreover, a hologram is a three-dimensional image that contains information about the size, shape, brightness, and contrast of the recorded object stored in a laser-generated interference pattern. Holographic projection is a holographic technique that records and reproduces real three-dimensional images to form images, which are holograms. Unlike a normal three-dimensional image, a hologram gives people amazing...
experience; it seems there is a real object visually. This is because holograms can bring about parallax; the existence of parallax can enable the observer to observe the image of different images by moving in different directions.

3. Basic Principle of Hologram

A hologram is a three-dimensional photographic image that appears to have deep meaning. Holograms are made by superimposing two two-dimensional images of the same object but different viewing angles. Holography requires a single precise wavelength of light; that is why the laser must be used. Reflection holograms are holography that can be viewed in normal light, with two laser beams and a photographic plate used to take images of objects. Both laser beams used in holograms spread the laser light like a flashlight through a beam of radiation. The coherence of the beam is lost, but an accurate wavelength is retained. One beam illuminates the object from the side, while the other (also known as the reference beam) touches the front of the object through a photographic plate, much like a conventional camera for two-dimensional imaging. The reflected light from the reference beam can leave an image or hologram on the photographic plate, and the object reflected by the measuring beam can also leave an image. The result is that a photographic plate records both images at the same time and produces a hologram. When we look at an object, each eye sees a sharp image that is slightly off the reference point. The brain integrates them into a three-dimensional image. The hologram is a man-made effect. The hologram is printed onto a set of ultrathin curved silver plates used for diffracting light. Diffraction is also the function of a prism, which breaks down multiple-wavelength white light into its own specific wavelengths. When white light hits a silver plate, the reflection diffracts each specific color, producing an offset image that looks somewhat similar to the original object’s color. The result is a three-dimensional image. A hologram is made up of an interference pattern between two original images.

4. The Optimization Algorithm of Pure Phase Hologram

The optimization algorithm of pure phase hologram [5, 7] is mainly to solve the optimization problem of pure phase hologram; that is, given a complex amplitude hologram, it is encoded into a pure phase hologram, and the phase-only hologram can be reconstructed by optical reconstruction. In addition, the original image must be reproduced as far as possible. After many iterative Fourier transforms, the resulting pure phase hologram itself produces phase errors. Through multiple iterations of Fourier transform and its inverse transform and imposing constraints on the holographic surface and the reconstructed image surface, respectively, when the final phase value is obtained, the mean square error of the amplitude in the positive and negative Fourier transform process will definitely decrease. There are three main types of phase-only holography optimization algorithms:

1. Iterative algorithm: the object holography approximation is usually used to start, through a series of repeated operations, and continuously optimize the approximate holography. Through this approximation, the reconstructed image can be obtained, such as Gerchberg–Saxton algorithm and error diffusion algorithm.

2. Noniterative algorithm: the approximate solution can be obtained at one time according to the specified steps without a lot of optimization computations, such as random phase method, sampling class method, mode mask and secondary phase mask method, dual phase method, and nonrandom phase method.

3. Other algorithms are various, each having its own characteristics, for example, direct algorithm, iterative and noniterative algorithm, phase extraction method based on Wirtinger Flow [7], and CGH algorithm based on depth learning. Although the noniterative algorithm is more suitable for real-time holographic display than other algorithms due to its lower computational load, its reconstruction quality is not as good as iterative algorithm.

4.1. Mathematical Iteration

4.1.1. Definition of Iterative Algorithm.

For a given system of linear equations \( x = Ax + B \) (\( x, A, B \) are all the same matrix and any system of linear equations can be transformed into this form), the method by which the formula \( x_{i+1} = Ax_i + B \) \((x_i)\) represents the \( x \) obtained by iterating \( i \) times and the initial value \( i = 0 \) is replaced step by step to obtain an approximate solution is called the iterative method (or the first-order stationary iterative method) [8]. If \( \lim_{i \to \infty} x_i \) exists and is represented by \( x^* \), then the iterative method is said to converge. Obviously, \( x^* \) is the solution to this system of equations, otherwise known as iterative divergence. In general, iteration is the process of solving a problem (usually an equation or a set of equations) by finding an approximate solution from an initial estimate in a numerical analysis. The methods used to implement in this process are collectively referred to as iterative methods. Iteration is an activity that repeatedly feeds back the problem-solving process, usually to get closer to the desired goal or result. Each iteration of the process is called “iteration” and the result of each iteration will be the initial value of the next iteration. Iterative algorithm is a basic way to solve the problem by computer. It mainly makes use of some characteristics of computer; that is, the speed of operation is fast and suitable for repetitive operation, so that the computer repeatedly executes a set of instructions.

4.1.2. Preparation Steps to Solve Problems with Iterative Algorithms. The first step is to determine the iteration variable. In general, there is at least one variable, iteration variable, which can be used to deduce the new value from the old value directly or indirectly. The second step is to establish
an iterative relationship. Iterative relationship refers to how to derive the relationship or formula of its next value before one iterative variable. The key to the iterative problem is to establish a suitable iterative relationship, generally using a method of recurring method or inverted method to get the desired iterative relationship. The third step is to control iterative processes. Since the iterative process cannot be executed in unlimited loop execution, the end time of the iterative process has become a problem that the iterative program must be considered. Usually control iterative processes can be divided into two cases of determined values and cannot determine the number of iterative times. The first case control iterative process can be implemented by building a repetitive cycle of a fixed iterative number; the second case controls the iterative process is more complex and needs to find the condition of the end of the iterative process.

4.1.3. Iterative Algorithm Application. The iterative algorithm can be applied to the approximate root of the equation or equation group [9]. The equation is \( f(a) = 0 \), using the mathematical method to derive equivalent form \( x = g(a) \), followed by following:

1. Select an approximate root of an equation to give the variable \( a_0 \)
2. Assign the value of \( a_0 \) to the variable \( a_1 \), then calculate the value of \( g(a_1) \), and assign the result to the variable \( a_0 \)
3. If \( |a_0 - a_1| \) is greater than the specified accuracy requirement, the calculation of repeating steps in (2) is returned

If the equation has root, the approximate root sequence calculated by the above method is converged, and \( a_0 \) obtained in the above method is the root of the equation. The above algorithm is expressed as the form of C language programs:

\[
A = (a_0, a_1, \ldots, a_{n-1}).
\]

The equation group is \( a_j = g_j(A) (j = 0, 1, \ldots, n-1) \).

4.2. Iterative Algorithm on Hologram. Gerchberg–Saxton (GS) algorithm is the most famous and probably the most used method of the iterative algorithm [8]. According to the amplitude distribution of the plane of the hologram and the reconstructed image, the phase information of the light field in the plane of the hologram is obtained by iterating the forward and backward light wave transmission and the restriction imposed on the two planes (see below). This method is very suitable for computing phase-only holograms. Using the GS algorithm of Fourier transform as an example, we first estimate the phase distribution \( \phi^{(0)} \), and then each iteration of the algorithm includes the following steps:

1. The initial phase-only hologram is \( H^{(n)} = \exp(i\phi^{(n)}) \), calculated to transfer the light field from the hologram plane to the image plane of the object:

\[
H^{(n)}_2 = F^{-1}(H^{(n)}_1).
\]

2. Limitation: replace the amplitude distribution of the light field transmitted to the image reconstruction plane in the first step with the required object’s amplitude distribution:

\[
H_{3}^{(n)} = A_{\text{target}} \exp(i \arg(H^{(n)}_2)),
\]

where \( A_{\text{target}} \) is the target image amplitude.

3. Calculate the propagation of the light field from the image plane of the object to the hologram plane in the second step:

\[
H_{4}^{(n)} = F(H_{3}^{(n)}).
\]

4. Restriction: set the amplitude of the light field transmitted to the plane of the hologram in the third step as Unit 1 to get the pure phase, the phase hologram \( P^{(n+1)} \):

\[
\phi^{(n)} = \arg(H_{4}^{(n)}),
\]

\[
P^{(n+1)} = \exp(i\phi^{(n)}).
\]

Go back to step 1, replace \( H^{(n)}_1 \) with \( P^{(n+1)} \) and continue iterating. When the accuracy condition is satisfied, \( P^{(n+1)} \) is output as a phase-only hologram [9–12].

The random phase method is a commonly used non-iterative method in the process of pure phasing of complex amplitude holograms. Since pure phase holographic coding is equivalent to a high-frequency filtering process, the reconstructed image only includes the boundaries and lines of the original image. Therefore, a random phase mask needs to be introduced to disperse the wavefront of the original image to the entire hologram to improve the reconstruction quality.

5. Calculate Hologram

The hologram is calculated by using artificial methods to encode the hologram, which is hologram made by computer and various plotters [13]. The process of computer-generated hologram is shown in Figure 1.

5.1. The Development of Computer-Generated Hologram. Computer-generated hologram, or CGH for short, was first proposed by Kozma and Kelly to make filters that could test noise-covered signals [9, 14]. Later, with the rapid development of computer technology and optical technology, it gradually developed into an independent branch of science. In 1948, Dennis Gabor first put forward the theory of “Wave-front reconstruction” [15] and then began to study the holography technology, which changed the current situation that the sensitive recording medium can only record the amplitude-related information of the light wave. The quality of the hologram is very low because of the weak coherence of the mercury lamp source. This is the first generation of holographic technology, that is, the use of
#include <stdio.h>
#include <math.h>
#define Epsilon 1.0E-8.

double g(double a) {
    double b;
    b = pow(a + 1, 1.0/3);
    return b;
}

int main(int argc, char argv[]) {
    double a0, a1;
    int k = 0, max = 20;
    printf("Enter initial approximation: ");
    scanf("%f", &a0);
    do{
        a1 = a0;
        a0 = g(a1);
        k = k + 1;
    } while(fabs(a0 - a1) > Epsilon && k < max);
    printf("Approximate root of equation is %f 
", a0);
    return 0;
}

Algorithm 1: Seeking the root of equation  \( f(a) = a \cdot 3 - a - 1 \) by iterative method.

#include <stdio.h>
#include <math.h>
#define Epsilon 1.0E-8.

int main(int argc, char argv[]) {
    double a[10], b[10];
    int cnt = 0, max = 100;
    double c = 0;
    for(int i = 1; i <= 4; i++) {
        a[i] = 0;
    }
    do{
        for(int i = 1; i <= 4; i++)
            b[i] = a[i];
        for(int i = 1; i <= 4; i++) {
        }
        c = 0;
        for(int i = 1; i <= 4; i++)
            c += (fabs(b[i] - a[i]));
        cnt++;
    } while(c > Epsilon && cnt < max);
    for(int i = 1; i <= 4; i++)
        printf("a[%d] = %f\n", i, a[i]);
    return 0;
}

Algorithm 2: Seeking the root of equation  \( f(a) = \begin{cases} 10a_1 - a_2 + 2a_4 = 6; \\ -a_1 + 11a_2 - a_3 + a_4 = 25; \\ 2a_1 - a_2 + 10a_3 - a_4 = -11; \\ 3a_2 - a_3 + 8a_4 = 15; \end{cases} \) by iterative method.
5.2. Overview of Computer-Generated Hologram. CGH can not only record all information of object light wave in real or virtual object, but also have a kind of physical depth of field which can be seen by naked eye, so it has great flexibility and unique advantage. With the development of optics, after the introduction of computer into the field of optical processing, many optical phenomena can be simulated by computer, but only holographic display can reproduce the information of the amplitude and phase of the light wave of the original object; the technique is called the ideal 3D display method because it can provide all the 3D information needed by the human eye, as if it can see the diffuse light field of a real object or scene. CGH is based on digital calculation and modern optics. It can record the phase and amplitude of light wave, low noise, and high repeatability and can record any nonexistent object.

5.3. The Procedure of Making CGH

(1) Sampling: sample the object surface or wavefront with a sampling theorem, thereby obtaining discrete values from the object or the wavefront at each discretization point.

(2) Calculating: the calculation of the light field distribution of the light wave on the holographic plane is specifically from the object to the hologram plane; during the propagation process of the photoelectric wave, the calculation of the reconstituting distribution of the light field on the hologram plane is passed by computer to process light wave.

(3) Encoding: the transmittance change of the hologram is to distribute the optical wave complex amplitude on the hologram plane in accordance with different coding methods.

(4) Completing: changes of hologram transmission through computer control, plotting a hologram with a plotter, computer-controlled micrometer, or cathode ray tube can also be directly recorded on a film hologram; if the drawing device does not have enough resolution, you will draw a relatively large chart and then reduce it to obtain a hologram.

(5) Reproducing: It is similar to reconstructing an optical hologram. The production process of Fourier transform hologram is shown in Figure 2.

In the sampling step, the total number of sample points required to be entered when the computer hologram is created by $N = (\Delta x \times \Delta y)^2$, where $(\Delta x)^2$ is an area of the input image and $(\Delta y)^2$ is its band area. There are two ways to enter the bandwidth of the input image. The first method is not unlimited because the frequency of the image forming system is not unlimited, and there is a cutoff frequency, which can be approximately an optical channel or the cutoff frequency of the receiver to represent the input image bandwidth [16, 17]. The second method is to use the definition of the local frequency to indicate the bandwidth of the product wave function: the bandwidth of the value wave function in the $x$ direction is $B_x$, and the bandwidth in the $y$ direction is $B_y$. Then

$$B_x = \frac{2}{\lambda} \left( \frac{\partial W(x, y)}{\partial x} \right)_{\text{max}},$$

$$B_y = \frac{2}{\lambda} \left( \frac{\partial W(x, y)}{\partial y} \right)_{\text{max}}.$$

That is, the bandwidth of the product wave function is indicated by twice the maximum value of the local frequency. In addition, the computer hologram, in the present, has not only optical, but also digital reproduction. Digital reproduction mainly utilizes two formulas: Fresnel diffraction formula and transmission coefficient formula of the lens [14, 15]. Fresnel diffraction formula:

$$E(x_0, y_0) = \frac{e^{ikz_1}}{i\delta z_1} e^{i\pi / \delta z_1 (x_0^2 + y_0^2)} F\{E(x_1 + y_1) \exp \left[ i \frac{\pi}{\lambda z_1} (x_1^2 + y_1^2) \right] \},$$

where $F$ represents Fourier transform, $i$ is the input surface retrieval, $p$ is the output surface of the output surface, $z_1$ is the distance between the two planes, $k$ is the optical wave, and $\lambda$ is the wavelength of light.
5.4. Types of Computational Holograms. With the continuous development of computational holography, many different types of computational holograms have appeared one after another. Their principles are similar but very different. These holograms are used in different occasions. According to the relative position of the three-dimensional object and the calculated overall coordinate position, it is divided into the image calculated hologram, the Fourier transform computed hologram, and the Fresnel computational hologram.

Image computed hologram: the object wave function is the complex wavefront recorded in the image computed hologram. After understanding the complex amplitude distribution function of the object’s image field when making the image computed hologram, the computer uses the coding method to calculate the transmittance function to obtain the transmittance distribution function of the image hologram and finally through the plotter and optics. The reduced version can be obtained like a computed hologram. The image hologram can directly reproduce the image of the original object.

Fourier transform computed hologram: the Fourier transform of the object wave function is the complex wavefront recorded in the Fourier transform computer hologram. When making the Fourier transform computer hologram, the computer uses the fast Fourier transform algorithm to Fourier the object light wave function. The leaf transform discretization process then calculates the transmittance distribution function of the Fourier transform computed hologram through the encoding method, and finally obtains the Fourier transform computed hologram through the plotter and optical reduction. The Fourier transform computed hologram can directly reproduce the Fourier transform spectrum of the original object.

Fresnel computational hologram: the Fresnel diffraction wave emitted by the object is the complex wavefront recorded by the Fresnel computer hologram. When making a Fresnel computed hologram, calculate the complex amplitude distribution of the Fresnel diffraction wave on a certain distance plane according to the object wave function, then encode the complex amplitude distribution into the transmittance function of the hologram, and finally pass plotter and optical reduced version can get Fresnel computed hologram. For planar objects, because there is no change in depth information, the Fresnel diffraction process of the wavefront can be calculated by simple integration.

In addition, according to the properties of the hologram transmittance function distribution, it can be divided into two types: amplitude type and phase type. In these two categories, it can be further subdivided into binary computing holography and gray-scale computing holography according to the characteristics of transmittance change. However, according to the coding technology used in the production of computational holography, it can be roughly divided into detour phase-type computational holograms, corrected off-axis reference light computational holograms, and computational holographic interferograms.

5.5. Sampling Theorem. If a time-continuous signal \( f(t) \) with a maximum cutoff frequency \( f_m \) is sampled by a switching signal with a time interval of \( T \leq 1/2f_m \), \( f(t) \) can be uniquely represented by the sample signal, and this is the sampling theorem.

The characteristic of optical image information is that it is often continuously distributed. Due to the limited information capacity of physical devices, while realizing information recording, storage, transmission, and processing, a continuous function often uses its function value on a set of discrete points. Sampled value is represented. Given that a function is \( f(n) \), its sampling value is

\[
 f(n) = f(t_0 + n\Delta x), \quad n = 0, 1, \ldots, N - 1. \quad (8)
\]

In the formula, \( t_0 \) is the sampling starting point, \( n \) is the sampling point number, \( \Delta x \) is the sampling interval, and \( f(n) \) is the sampling value or sequence of sampling values. In principle, the smaller the sampling interval is, the more accurately the sampling sequence can reflect the original continuous function. Sampling is an important and
indispensable step in the production of computational holograms, and the sampling theorem is one of the important theoretical foundations in computational holography technology.

5.6. Calculation. The process of calculating the hologram of an image is the way of using the laws of physics to obtain the complex amplitude distribution on the holographic plane and using the computer to simulate the propagation, diffraction, and interference of light, which obtain the complex amplitude distribution on the holographic plane. In specific calculations, Fourier transform, Fresnel diffraction formula, etc. are often used. The classical scalar wave diffraction theory is used in computer holography. This theory treats light waves as scalar waves and can well explain the holographic process.

5.7. Coding of Information. Coding is to realize the complex amplitude (amplitude and phase) of each sampling point of the spectrum calculated above by artificial method according to the given reproduced illumination light wave. Computational holography can “lock” phase and amplitude information through two approaches:

1. Interferometry coding method: the phase information is “locked in” by the interference of the reference light wave and the object light wave, and the transmittance function is calculated by the computer [13, 15].

2. Circuitous phase coding: when encoding the amplitude or phase of the object function, it is necessary to use two independent parameters to separate on the hologram. The amplitude encoding of the light wave needs to be achieved by controlling the transmittance or the aperture area of the small cell on the hologram. The phase is encoded by the position of the rectangular hole, and there is no need to refer to the light wave or increase the bias component during the recording process.

5.8. Storage and Reconstruction of Hologram. The storage of the original image called hologram is made by computer-controlled drawing equipment, and the image size is appropriately enlarged or reduced. The required hologram can be obtained on the negative film by obtaining the shooting record. In addition, the amplitude type computer-generated hologram can be made by using pattern generator, photo plotter, microdensitometer, and laser beam scanning recording device. The reconstruction method of computer-generated hologram is determined according to the type of hologram, and it is also related to the coding method of information.

6. Application and Prospect of Hologram

6.1. Application of Hologram. Holograms have many uses in art, science, and technology, such as the following.

6.1.1. Copper Crafts. Use 3D Max or C4D modeling software to obtain the 3D model of copper crafts, import the obtained 3D model into Adobe After Effects Software for processing, and make the holographic projection of copper crafts, that is, get the hologram of copper crafts, which is conducive to the collection of copper crafts data.

6.1.2. Transmission Holographic Projector. The principle of holographic projection technology [18]: holographic projection technology belongs to a presentation method of 3D technology, which originally refers to the technology of recording and reproducing the real three-dimensional image of an object by using the principle of interference and diffraction. Regardless of where the laser and hologram plate are placed in a transmission holographic projector, they are placed at the same distance and angle. Turn on the laser and you will get an exact copy of the original image, which is seen as a virtual image. Place the laser head upright from the hologram board for a sharper image. Depending on the lighting angle, the viewing angle and the quality of the image will be changed and different; moreover, the image quality will be improved when illuminated from the front.

6.2. The Prospect of Hologram

1. In the composite light composed of multiple wavelengths, only one wavelength, that is, the light with the same wavelength as the recording light
wave, can achieve the maximum diffraction, while the diffraction image with sufficient brightness cannot appear at other wavelengths, so as to avoid the occurrence of color crosstalk, so the volume hologram can be used for white light reproduction. In addition, volume holograms can store multiple three-dimensional images at small angular intervals without image crosstalk. Therefore, volume holograms can also be used for high-capacity and high-efficiency holographic storage.

(2) Some practical CGH elements are fabricated, such as aberration corrector for correcting the aberration of ordinary holographic elements, a laser scanner for realizing simultaneous high-speed scanning of multiple beams of light, and a phase shifter for encoding in data storage. It is used for holographic lens with special function.

(3) Computer-generated hologram can display three-dimensional images of objects that can be easily described by numbers but are difficult to be actually made; that is, it can be displayed by hologram; CGH can also be used in optical detection, and its standard wavefront has high precision.

(4) In recent years, holographic projection technology has developed as high-tech. This technology interprets the concepts of function and form, as well as design and art, and applies holographic projection technology to landscape design to explore new technical means. It can be seen from the development of holographic projection technology that high technology will be applied to all aspects of future life. Especially in the application of environmental design, it has important breakthrough significance for the development of environmental design.

7. Conclusion

3D holographic projection technology as a prevailing visual high-tech has been very popular in recent years. The stereoscopic images (holograms) reconstructed by holographic technology are helpful to preserve precious works of art for collection, and computer-generated holograms can also give engineers and designers’ designs unprecedented visual effects. In the near future, holograms may be used to store information. The future development potential of holograms is huge. It is believed that, with the improvement of technology, the subsequent development will provide more satisfaction and make greater contribution to the progress of human society.

Data Availability

All data used to support the findings of this study are available from our experiments, and these data are publicly available data. Upon request, please contact the author to provide them.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This paper was supported by Top-Notch Talents Cultivation Project of Anhui Higher Education (gjxgfx20200099), Anhui Natural Science Research Project (2020) under Grant no. KJ2020A0696, Key Research and Development Projects of Tongling Science and Technology Plan (20200201016), Special program of copper culture of Tongling University (2020lxxytw02), and Anhui College Students’ Innovation and Entrepreneurship Program (s202110381314).

References

holographic projection,” *Optics and Lasers in Engineering*, vol. 147, no. 12, Article ID 106748, 2021.


