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Weighted 3D GS algorithm for image-quality improvement of multi-plane holographic display

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Abstract　Theoretically，three-dimensional (3D) GS algorithm can realize 3D displays；however，correlation of the output image is restricted because of the interaction among multiple planes，thus failing to meet the image-quality requirements in practical applications. We introduce the weight factors and propose the weighted 3D GS algorithm，which can realize selective control of the correlation of multi-plane display based on the traditional 3D GS algorithm. Improvement in image quality is accomplished by the selection of appropriate weight factors.

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1　Introduction

Holography，especially computer holography，is a promising method of realizing three-dimensional (3D) displays [1,2]. Holographic display is a technique that realizes true 3D display. It can record the phase，which reflects depth information，and reproduce completely the object wave. In recent years，research on laser computer holographic 3D display，especially the research on real-time fast algorithm for laser computer holographic 3D dynamic display，has drawn the extensive attention of researchers. The general algorithms used in computer holographic display field are the GS，direct binary search，simulated annealing (SA)，genetic algorithm (GA)，and SA-GA. The GS algorithm，proposed by Gerchberg *et al*. in the 1970s，is an optimization algorithm used to compute phase-only hologram[3~5]，and it features advantages in practical application in terms of lesser time consumption. Based on the original GS algorithm，3D GS algorithm is developed by introducing the focusing lens factor for multiple planes. A 3D object can be divided into multiple planes，and 3D display can be realized using multi-plane display technique[6,7]. The correlation coefficient (Co) between the iterative and the original images is chosen to evaluate the algorithm and the reconstructed image quality，which is defined by

$$Co(t,t_0) = \mathrm{cov}(t,t_0)(\sigma_t \cdot \sigma_{t_0})^{-1}, \qquad (1)$$

where $\mathrm{cov}(t,t_0)$ is the cross covariance between t and t_0，σ is the standard deviation，t_0 denotes the original plane，and t represents the reconstructed image. The Co value ranges over $[0,1]$. The maximum value of one indicates that t is perfectly correlated with t_0，and the correlation corresponds to the quality of the reconstructed images.

The correlations of the multiple planes are restricted because of the interaction of the multiple planes；thus，this method does not meet the high image-quality demand in practical applications. In this paper，with the aim of increasing the correlations and improving the image quality，weight factors are introduced based on the traditional 3D GS algorithm，and weighted 3D GS algorithm is proposed. Thus，selective control of the correlations of multiple planes can be realized，and the reproduced image quality can be improved by selecting the appropriate weight factors. The simulated results of weighted 3D GS algorithm for multi-plane display are analyzed and compared with those of the traditional 3D GS algorithm. Its function and the improvement in the reproduced image quality are also evaluated.

2　Traditional 3D GS algorithm

2.1　Introduction of traditional 3D GS algorithm

The original GS algorithm is applied to the iteration of single input and output planes. 3D objects can be divided into multiple planes，and 3D displays can be realized in every plane[7]. To display the multiple planes at different positions，the focusing lens factor is introduced in the original GS algorithm，and the 3D GS algorithm is developed. Figure 1 shows the flowchart of the 3D GS algorithm[6].

2.2　Disadvantage of traditional 3D GS algorithm

Matlab programming and simulation of the traditional

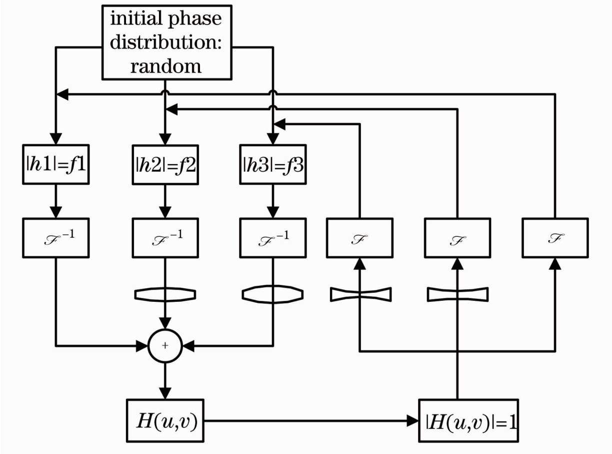

Fig. 1 Flowchart of the 3D GS algorithm.

3D GS algorithm for a two-plane display were performed. The $g1$ and $g2$ images of the two planes are both gray-level images with 256 pixel × 256 pixel. The operating wavelength was 532 nm. The distances from the reconstructed images to the hologram plane for the two planes were 0.9 m and 0.2 m, respectively. The sampling point was 256 pixel × 256 pixel, and the sampling interval was 8 μm. Figure 2 shows the reproduced images of the traditional 3D GS algorithm under the best situation. To eliminate image influence, two similar pictures were used, with one rotated so that it can be distinguished from the other. The inverse Fourier transformation sequence of the two planes in the algorithm leads to restricted correlation in the first plane. Therefore, the correlation criterion of the first plane cannot be made too high; otherwise, the algorithm will not converge. In addition, the two planes interact with each other. As a result, the correlations of the two planes are constrained (they can reach only up to 0.94 under the best condition). However, higher correlation and reproduction of clearer images are always required in practical applications. The other problem lies in the contradiction between the number of plane divisions and the correlation results, i.e., the more the plane is divided, the lower is the correlation. Therefore, the application of traditional 3D GS algorithm suffers from some limitations.

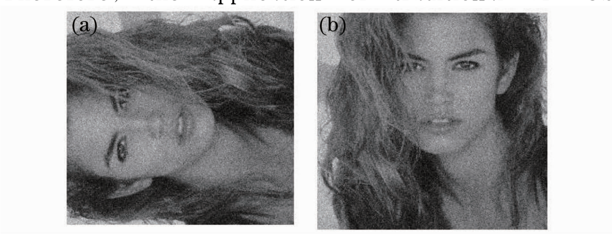

Fig. 2 Reproduced images of the traditional 3D GS algorithm under the best situation (the correlations are 0.9400 and 0.9399, respectively). (a) The first plane; (b) the second plane.

3 Weighted 3D GS algorithm

3.1 Introduction of weighted 3D GS algorithm

Based on the traditional 3D GS algorithm, the weight factors are introduced in two parts—one is the reading in of the amplitude of the input images, and the other is the addition of the complex amplitudes of the different planes after inverse Fourier transformation. The weighted 3D GS algorithm is consequently formed. Figure 3 shows the flowchart of the weighted 3D GS algorithm.

3.2 Significance of the weight factors and the weighted 3D GS algorithm

A, B, and C denote the modulation of the read-in amplitude of the ideal image. D, E, and F represent the weight of the hologram addition in the multiple planes. Increasing the D, E, or F value increases the weight of hologram addition for the corresponding plane, thus increasing the correlation of the corresponding plane. The correlation of the other planes can be reduced, and A, B, and C can be used to compensate for this reduction. Increasing the A, B, or C value increases the read-in amplitude of the image and, obviously, can increase the correlation of the corresponding plane. Therefore, A, B, and C can help in the compensation of the reduced correlation of the other planes. By selecting appropriate values for parameters A, B, C, D, E, and F, the correlations of the three planes can be selectively increased based on the requirement (the correlations can be improved compared with that of the traditional 3D GS algorithm). The quality of the reproduced images can also be improved.

3.3 Analysis of the simulated results of the weighted 3D GS algorithm for two-plane holographic display (the weight factors are A, B, D, and E)

Computer simulations for a two-plane holographic display with weighted 3D GS algorithm were performed. Images $g1$ and $g2$ were all gray-level image with 256 pixel × 256 pixel. The operating wavelength was 532 nm. The focal length and the distance from the reconstructed image to the hologram plane for the two planes were 0.9 m and 0.2 m, respectively. In our experiment, Matlab was used to compute the hologram and to perform the numerical simulations. The sampling point was 256 pixel × 256 pixel, and the sampling interval was 8 μm. From the analyses of various A, B, D, and E values and the simulated results, conclusions can be drawn as follows.

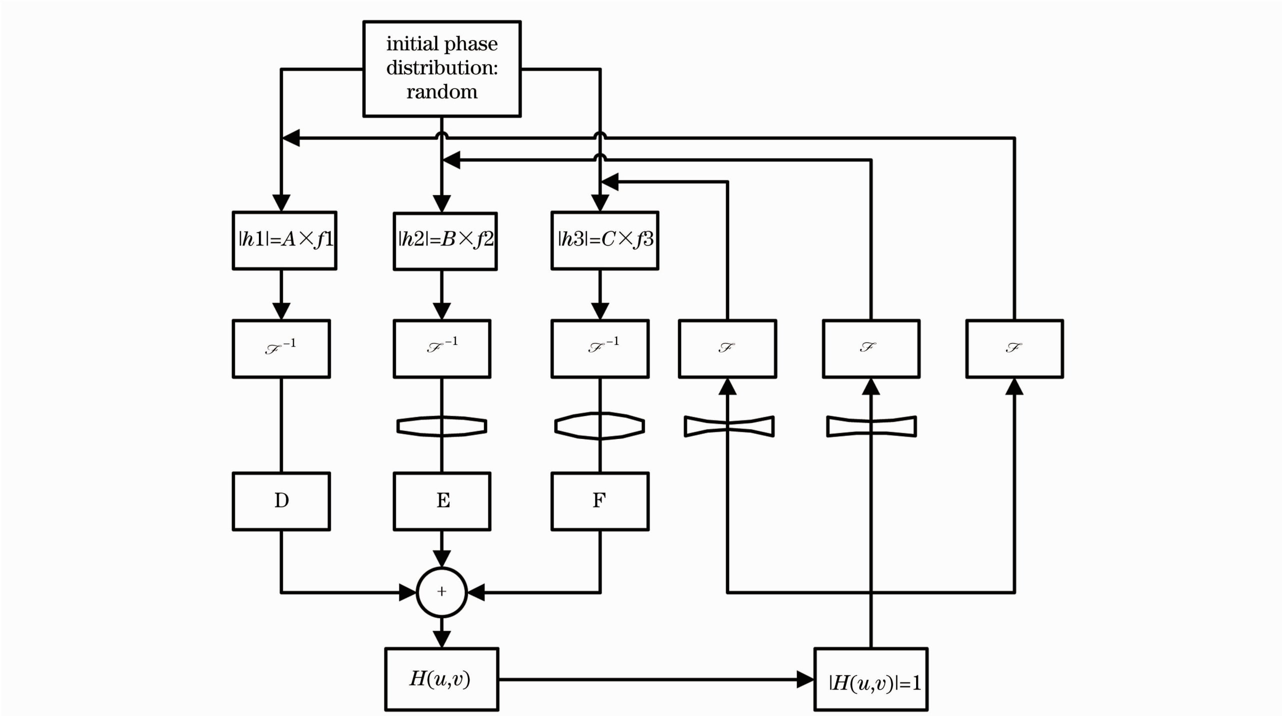

Fig.3 Flowchart of the weighted 3D GS algorithm.

3.3.1 Role of parameters D and E

The weight factors D and E are used to change the weight of hologram addition in the two planes, and they are critical to the correlation of the two planes. If D is higher than one and E is lower than one, then the weight of the hologram addition in plane 1 is higher than that of plane 2. If the correlation of the first plane is increased, the correlation of the second plane is reduced, and vice versa. For example, when $D=2.5$ and $E=0.7$, the correlation in the first plane can reach up to 0.9860, but that of the second plane can only reach up to 0.8634. As a result, improvement in the reproduced image quality in one plane is realized. Different D and E values exhibit different correlation results. If image-quality improvement is desired in the first plane, the D value must be selected to be higher than one and the E value must be lower than one, and vice versa. The best values for D and E can be selected according to our requirement and the simulated results. In addition, changing the D and E values can change the convergence of the algorithm. If D is higher or E is lower, the convergence in the first plane improves, and that of the second plane decreases, and vice versa. Figure 4 shows the aforementioned conditions.

3.3.2 Role of parameters A and B

The function of parameters A and B is to enhance or attenuate the read-in amplitudes of the input images and increase or decrease the correlations of the two reproduced images. However, evaluation of their influence shows that the effect of A and B is inferior to

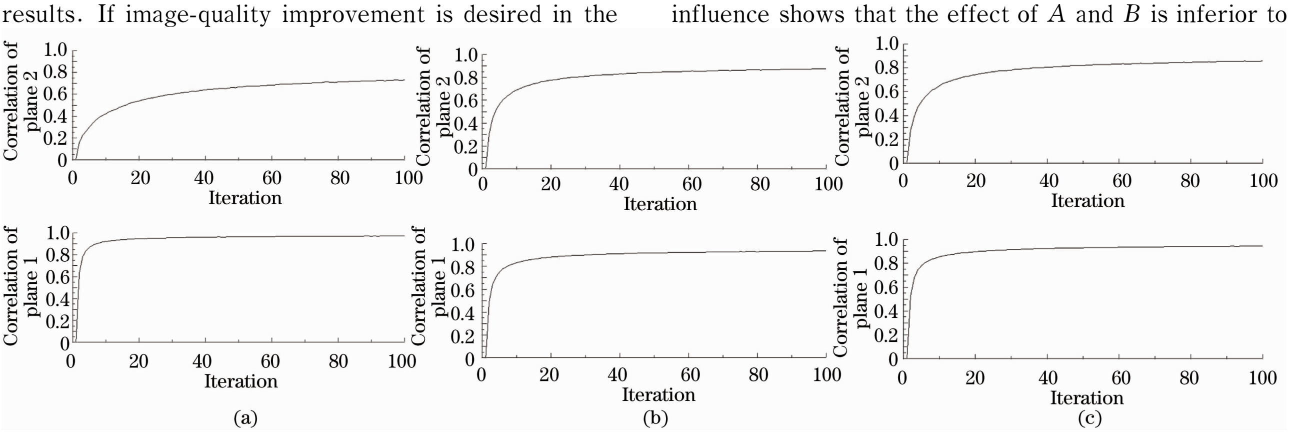

Fig.4 Convergence properties for different D and E values. (a) $D=2.5$, $E=0.7$; (b) $D=1$, $E=0.7$; (c) $D=2.5$, $E=1.5$.

that of D and E, i. e., they are of secondary importance. By selecting appropriate D and E values to improve the correlation of one reproduced image, proper selection of A and B values can offset the correlation of the other image; thus, the integral correlations of the two planes can be improved.

3.3.3 Increase in the correlations of the reproduced images

By selecting appropriate values of A, B, D, and E, the correlation in the first plane can reach up to 0.9860, and that of the second plane can reach up to 0.9859, under the best condition (the evaluation criterion is the sum of the two correlations). In comparison, the correlations can only reach 0.9400 and 0.9399, respectively, using the traditional 3D GS algorithm. Correspondingly, the correlation of the other plane reaches approximately 0.87. Figure 5 shows the comparison of the images reproduced by the weighted and the traditional 3D GS algorithms, which shows an obvious difference. Figures 6～8 show the correlations of the two planes with the increase in the iteration under three conditions. The convergence of the correlation needs more iteration in case of complicated images. Table 1 shows the comparison of the weighted GS algorithm with the original GS algorithm. The results show that this method can improve the image quality of one plane, as previously mentioned, even if the correlation of the second plane decreases.

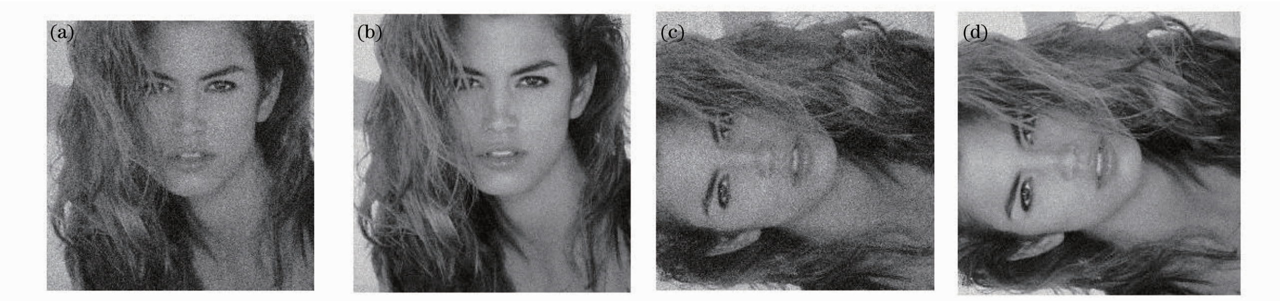

Fig.5 Comparison of the images reproduced with weighted and traditional 3D GS algorithms. The first plane using (a) traditional algorithm and (b) weighted algorithm; the second plane using (c) traditional algorithm and (d) weighted algorithm.

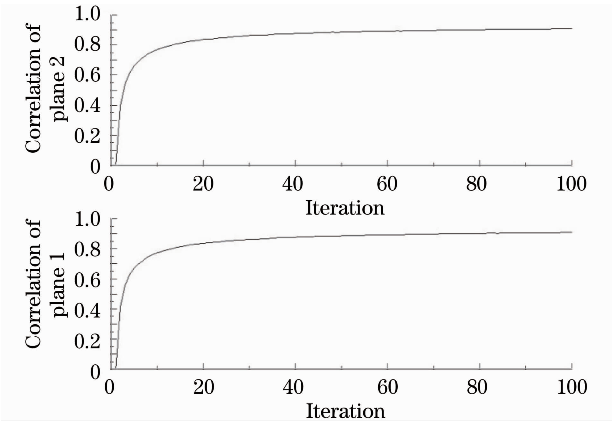

Fig.6 Correlations of two planes by increasing the iterations using the traditional algorithm.

When the distance between the reconstructed planes is close enough, for example, 0.1 mm, crosstalk, known as an inherent problem of the GS algorithm, could possibly appear, which must be overcome. When the image number increases, more weight factors are required, and the weighted GS algorithm can still be effective except for the adjustment and the appropriate selection of values of the weight factors. For 3D objects, the distance between adjacent planes is very small; thus, holograms calculated with different focus lens can be superimposed using different sampling rates into one hologram.

Using this weighted algorithm, selective improvement in the reproduced image quality in multiple planes can be realized, and 3D images with special effects can be obtained.

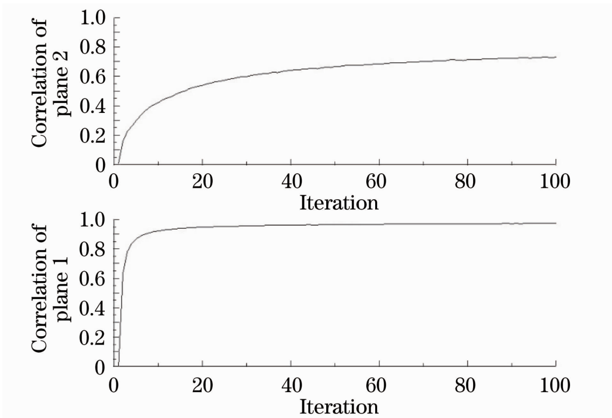

Fig.7 Correlations of two planes by increasing the iterations using the weighted algorithm (D = 2.5 and E = 0.7).

4 Conclusion

In this paper, an improved algorithm is presented via the introduction of weight factors into the traditional 3D GS algorithm. When the values of these factors are selected appropriately, selective improvement in the

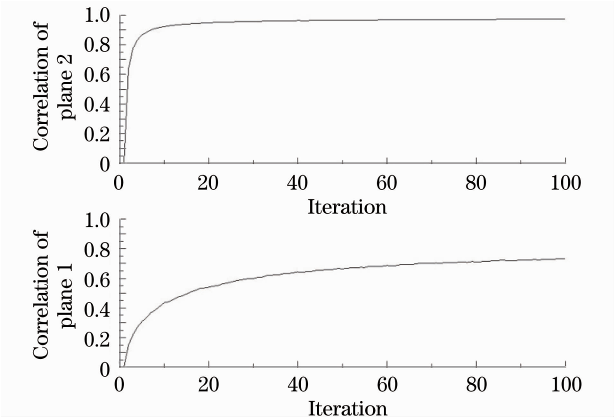

Fig.8 Correlations of two planes by increasing the iterations using the weighted algorithm ($D = 0.7$ and $E = 2.5$).

Table 1 Comparison of the weighted GS algorithm with traditional GS algorithm

		Weighted GS		Traditional GS
		$D = 2.5$, $E = 0.7$	$D = 0.7$, $E = 2.5$	
Plane 1	Correlation	0.9860	0.8634	0.9400
	Convergence (iteration number)	10	50	20
Plane 2	Correlation	0.8600	0.9859	0.9399
	Convergence (iteration number)	50	10	20
Iteration		2,976	7,972	1,208

image quality and clearer image output can be realized. Although simultaneous improvement of two images cannot be readily realized by this algorithm, its advantage in improving the quality of the reproduced image in one plane can provide significant contribution in practical applications. Selection of appropriate initial phase distribution or improvement of the GS algorithm to obtain higher correlation and better convergence would be the next step in further improving the process [8, 9].

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