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Image Quality Assessment for Holographic Display

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Abstract

The measurement and assessment should be accompanied on any type of electronic displays. Especially, quantitative analysis is indispensable as the reference to catch the direction to proceed. In this paper, we will present the approach for quantification of the holographic display images. To do it, we achieved the holographic display system with spatial light modulator and Fourier lens, and adopted indices needed for evaluation, such as contrast ratio, cross talk, color dispersion, and uniformity. These indices have been generally employed in the field of classical 2D display and multi-view 3D display. However, there have been almost no tries to adopt them in that of holographic 3D display system due to the absence of concrete methodology up to now. We suggested a standard image, and identified that measured numbers could be used to select the better way of generating the holographic image. We believe that this quantitative approach for assessment of holographic images will help more accurate and systematic development in that field.

Introduction

Every display system needs the assessment process to know where to proceed, as a sailor could use the mariner's compass in the sea. In the field of classical 2D display and multi-view 3D display, several critical indices have been adopted and used for the assessment of images. For the holographic display, however, there are few attempts to evaluate and assess the quality of its images. This is attributed to the intrinsic difficulties in realization of the holographic display that is known as the most natural and most challenging technology in the field of electronic display [1][2].

Recently, there is a significant paper which analyzes the hologram by evaluating the diffraction efficiency (DE) and the peak signal-to-noise ratio (PSNR) [3]. Nevertheless, as the author in the paper mentioned, the assessment and evaluation of its images is not a matured technical field yet.

In this paper, we will present the approach for quantification of the indices needed for evaluation, such as contrast ratio, cross talk, color dispersion, and uniformity in the holographic system. To carry out the assessment, we achieved the holographic display with the off-axis manner, and suggested a suitable standard picture. The computer generated hologram signal is calculated through the algorithm of wave optics and the Fourier transform.

Realization of the Holographic Display

Setup for the Experiment

To measure quantitatively the image quality of the holographic display, we achieved a holographic display system (see Figure 1 [4]). We utilized two independent light sources with proper coherence, and a Fourier lens to focus the light into the observer's both eyes. Liquid crystal displays (LCDs) are used as the spatial light modulator (SLM), and the imaging camera is set at the viewing distance of 1m from the display. The distance between the SLM and the holographic object is called as depths here, and the imaging camera is focused best at each target depth. After taking the pictures of the holographic object's images, we analyzed them and calculated the number of indices.

Computer-Generated Hologram

We assumed that the wave function from the SLM propagates to the retina through the eye lens, and makes the holographic object at the target position in the air [5]. By setting the focal length of the eye lens to match the object we can calculated Fourier transform of the raw image for the computer-generated hologram (CGH) signal. Then the holographic objects can be observed when the observer's eyes or a camera is placed properly in the viewing window [6].

Here we applied the off-axis manner to obtain the final CGH signal [7]. To avoid the DC noise, we engraved grating pattern in the middle step of making CGH signal, and made the spot of wanted image located in the viewing window between the DC

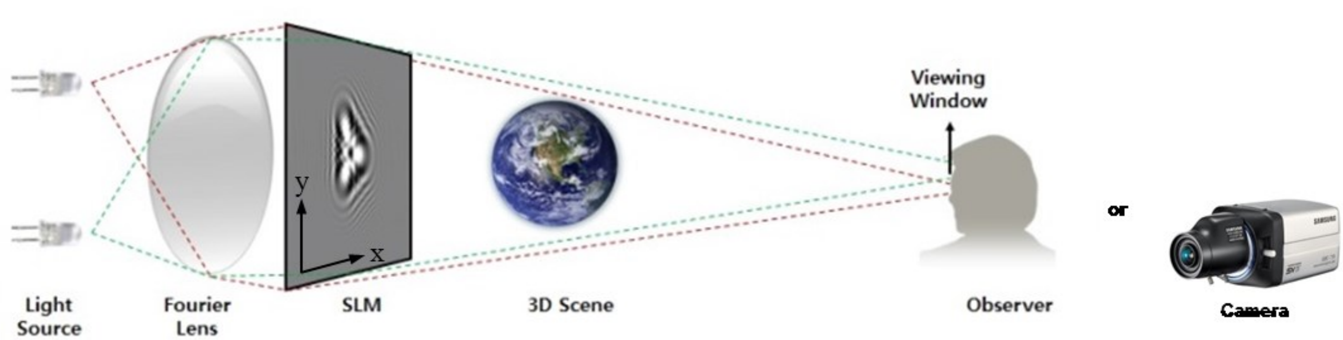

Figure 1. Experimental setup for the realization of the holographic display

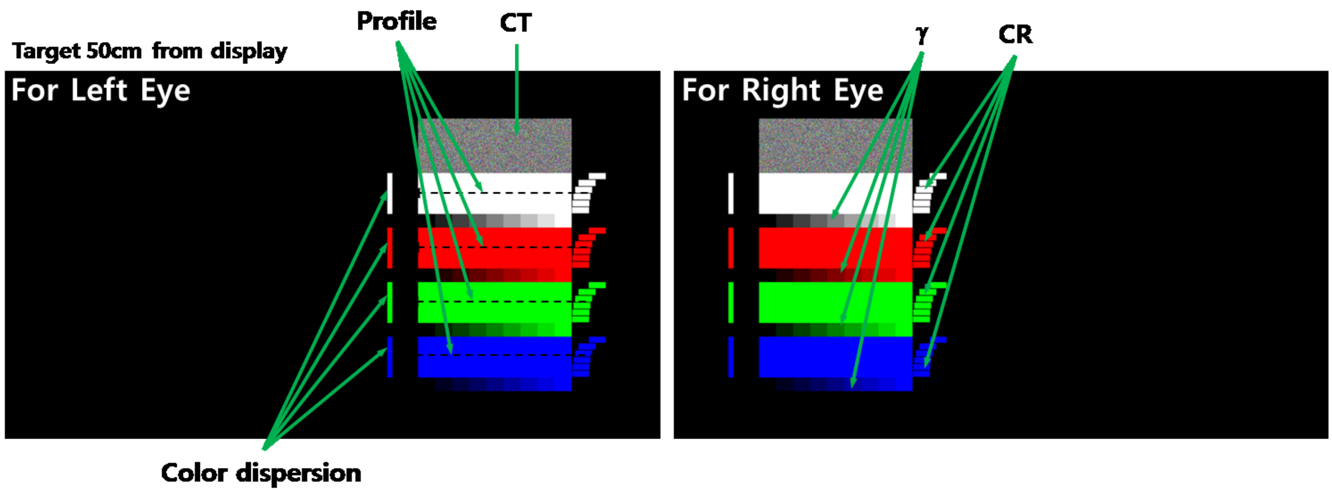

Figure 2. Standard image suggested for the assessment of the image quality. The indices to measure in the image are marked with the green arrows.

noise spots. In our operating system, the holographic display can show not only the static image, but also the video images by calculating the CGH in real time.

Assessment of the Image Quality in Hologram

Suggestion of the Standard Image

To quantify the indices of image, we introduced proper standard raw images to make a computer-generated holographic(CGH) signal, which include several sub-structural parts for quantifying contrast ratio(CR), cross talk(CT), color properties, distortion and uniformity of the holographic image (see Figure 2).

The small rectangles indicated by the arrows of CR are apart rightwards from the wide area with different distances horizontally, and the measured intensity of the interspace area contributes as a denominator when we estimate the CR for each interval. This interval is used to recalculate the corresponding spatial frequency with the unit of cycles per degree (CPD) for 6 cases.

Due to the diffractive property of the periodic structure and random scattering factors in an SLM, the image for one eye sometimes trespasses on the other eye's pupil. By introducing intentionally the random pattern as like a source of scattering, we try to know how much the CT happens.

The factor of nonlinear operation γ has usually the number of 2.2 for a normal panel. Here, we try to measure the γ of the holographic image by using the gradation for white and each color.

Color dispersion can be generated due to the inaccuracy of the CGH signal. All the narrow rectangles are located in the same position vertically on the standard raw image. When we observe the holographic object, they might be positioned differently against the raw image because the colors may not be focused at the right place depending on the CGH method.

Profile fluctuation is measured as the standard deviation of the intensity along the horizontal straight line. This is an important factor because when a person observe the holographic object in the air, an uneven surface can be quite offensive on the eyes.

To measure the distortion, we just adopt a checker board image, and calculate the quantity on the picture taken by the camera. To measure the uniformity, we make a CGH of full white and calculated the area that has over the 80% of the maximum value on the picture taken.

Comparison of the CGH Methods by Using the Standard Image

We induced various methods to make the CGH for the SLM, and select two which show good quality of images by the naked eyes [8]. Actually, after Fourier-transforming of the raw image, the wave function comes to have the complex number, and we need to encode this complex number into the non-negative real number for the SLM signal. The method 1 is that we take only the real part of the complex number, and set all the negative values to zero. The method 2 is that we sum the real part and the absolute value as the input signal. Of course, during the encoding process, the information loss is inevitable, and it is the key point to minimize the loss for the final CGH signal. In this experiment, we utilized two methods descripted above, and compared the indices that are measured from the pictures of the suggested standard image, shown in Figure 3.

In the table 1, each CGH method 1 and 2 shows all the indices mentioned in the above part. Apparently, the method 2 gives superior numbers almost for all the indices. Just seeing this table, we can easily identify the best method to make the CGH signal. The 0cm and 50cm mean the depth of the holographic object.

Actually, all the indices are affected by the total imaging system of the camera. In now status, just for the quick and easy decision, this effect was not corrected. In the future work, this should be considered and the standard measurement system should be also established.

Application results with CGH Method 2

As the result of adopting the CGH method 2, we can obtain the holographic objects and video movies of clear and vivid state. Figure 4 and 5 are still shots taken by the camera during the play of video movie. By our developing the elaborate techniques and algorithm for the CGH signal, the pictures themselves show quite clear and vivid images.

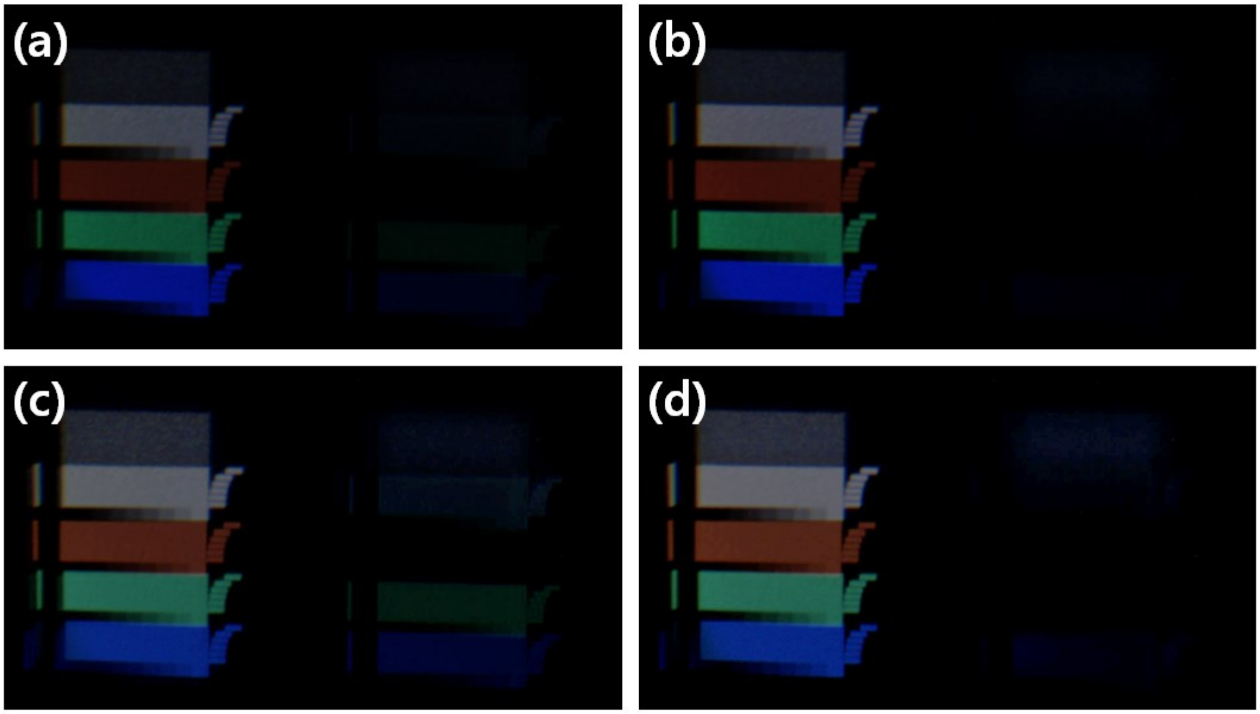

Figure 3. Pictures of the standard image taken by the camera. Here, all are taken at the depth of 50cm. For (a) and (c), CGH Method 1 is used. For (b) and (d), CGH Method 2 is used. The picture (c) and (d) are adjusted from (a) and (b) respectively by reducing intentionally the contrast 40% in the graphics program, so that we can exaggerate especially the CT. Clearly the method 2 shows lower CT than the method 1.

Table 1. Comparison of the CGH methods

Iindices		CGH Method 1				CGH Method 2			
		White	Red	Green	Blue	White	Red	Green	Blue
Contrast Ratio	0cm	128.6	51.3	122.7	55.6	300.7	76.1	185.3	113.7
	50cm	95.1	472.0	413.6	95.1	141.8	614.7	1288	138.9
Cross Talk	0cm	9.2%	3.1%	18.1%	20.6%	1.9%	0.2%	2.1%	4.1%
	50cm	6.4%	0%	12.5%	14.0%	0.7%	0%	0%	3.0%
γ	0cm	2.95	3.11	2.95	2.63	3.33	3.51	3.33	3.26
	50cm	2.32	2.61	2.15	2.02	2.45	2.83	2.49	2.42
Color Dispersion	0cm	0.53’	-0.42	0’	1.06’	0.85’	-0.42’	0’	1.06’
	50cm	0.42’	-0.85’	0’	0.85’	0.64’	-0.64	0’	0.95’
Profile Fluctuation	0cm	15.3%	10.8%	35.4%	23.4%	3.9%	6.2%	3.4%	3.8%
	50cm	4.5%	6.2%	4.6%	4.8%	4.2%	6.0%	4.4%	6.5%
Distortion	0cm	-	-1.5%	-	-	-	-1.0%	-	-
	50cm	-	0.39%	-	-	-	-0.7%	-	-
Uniformity	0cm	92.6% (full white)				93.5% (full white)			
	50cm	93.0% (full white)				93.4% (full white)			

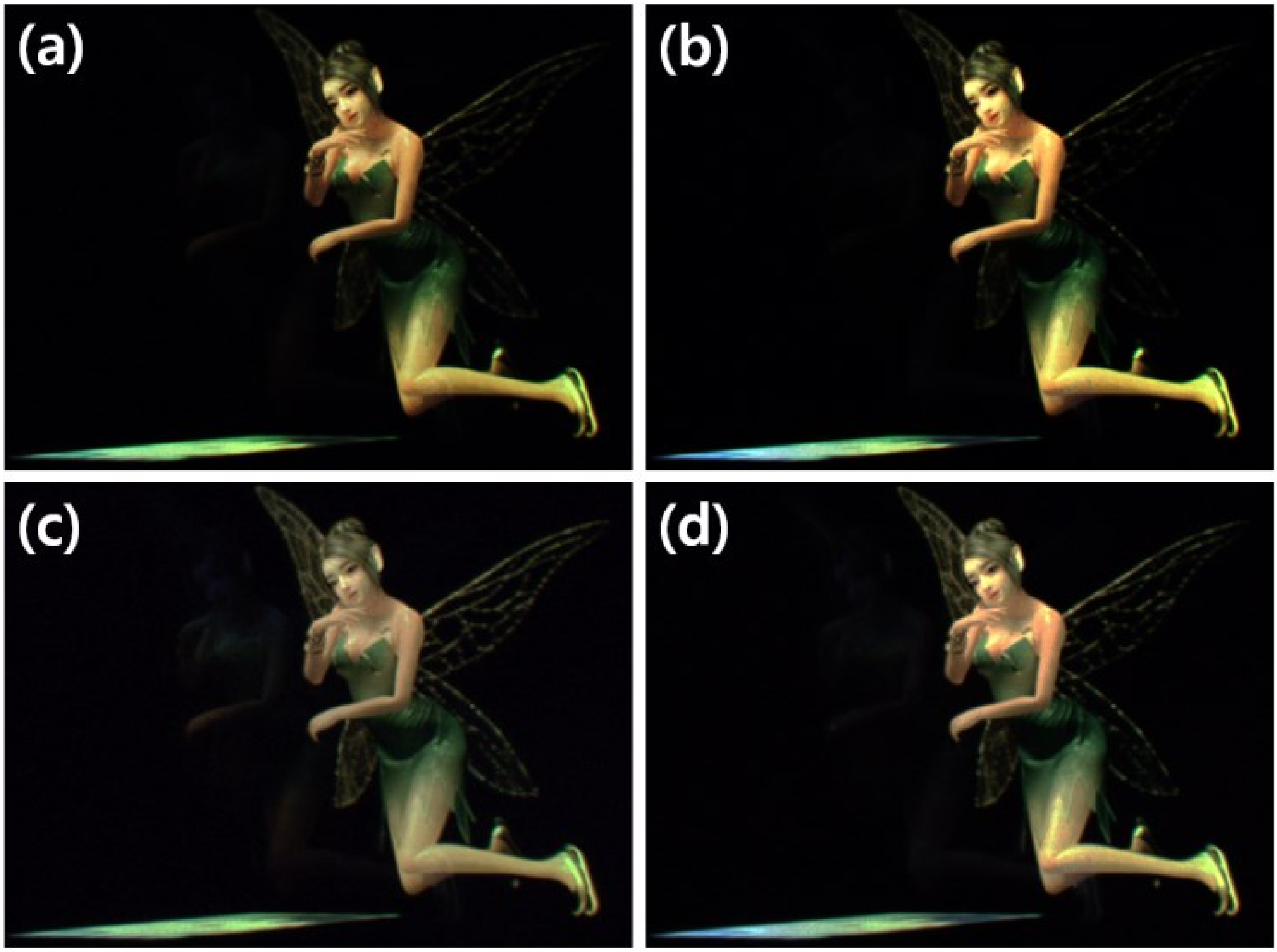

Figure 4. Fairy images taken by the camera as a still shot during playing the video movie. All are taken and processed in the same condition with Figure 3. The depth is 40cm. As the same results with the Figure 3, the CGH Method 2 shows lower CT than the Method 2. Please notice the hands and thighs of the fairy to compare the CT value.

Conclusion

We could obtain the numbers of indices for image quality in the holographic display. We applied two different methods of generating CGH signal for SLM, and could identify that most of indices are superior when applying the method #2 rather than #1. We think that our approach can help more accurate and systematic development in field of holographic display by quantifying the image quality.

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Author Biography

Wontaek Seo received his BS in physic (2004) and his PhD in quantum optics (2011) from the Seoul National University. Since then he has worked in the Samsung Advanced Institute of Technology in Samsung Electronics. His work has focused on the development of optical devices and the improvement of the image quality in the holographic display.