The Impact Of Environmental Factors On Image Qualities Of Holographic Projection

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This study primarily investigates the variations in image quality resulting from environmental factors in holographic projection, with the external environment being considered as a variable. The overall research employs a combination of experimental methods. The single-sided holographic projection experimental test chamber is set up to simulate experimental conditions. Simulation tests are conducted to evaluate the impact on images, capturing images of the reflective screen for three predefined environmental variables: background light intensity, background light color and background color. OpenCV image analysis software is employed to quantitatively analyze the image quality. The content of image quality analysis focuses on the average color of R/G/B, contrast, sharpness, and saturation. The study reveals that there is minimal contrast difference between white light and yellow light sources; however, under low illumination, white light outperforms yellow light in sharpness, while yellow light exhibits superior saturation. In high ambient light conditions, both white light and yellow light show a decreasing trend in contrast. When background color changes, image quality is generally better on a black background compared to gray and white backgrounds. This research provides a profound understanding of the impact of external environmental factors on holographic projection, contributing insights into the changes in image quality and the quality control of future holographic projection settings.

Keywords: Holographic projection; OpenCV; environmental factor; image quality

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1. Introduction

Due to the advancement of projection technology, the modes of expression in the field of projection art have greatly evolved. The integration of these emerging technologies in digital art exhibitions has enhanced the overall visual appeal of these events. Among the various emerging performance formats, holographic projection has garnered significant attention, with related technologies becoming more refined and widespread. In fact, holographic projection technology represents a reverse presentation of photographic principles, primarily leveraging the optical reflection properties of mirrored surfaces. While the images are initially two-dimensional, the use of pyramid reflective surfaces imparts a sense of depth to viewers, creating the illusion of 3D imagery and transforming images into seemingly tangible virtual forms [1].

Holographic projection provides a pseudo-3D visual experience without the need for additional equipment, enabling viewers to perceive virtual scenes or images that appear three-dimensional. This exhibition format is currently widely utilized in museums, product displays in shopping malls, and fashion events. In the research of Hua et al. [2], a method of evaluating cable status using computer calculations was developed, which provides great help for industrial applications. Similarly, the computer evaluation results of this study are also hoped to be used as future holographic projection designs. It can be used as a reference for evaluating performance environmental conditions, so that the visual effects of projection performances can be further improved.

The equipment for holographic projection consists of two main components: an image projection device, which may be a display screen or a set of projectors to project images onto a reflection screen, and the reflective screen that presents the projected content images, which are the virtual images visible to the viewer. In general, the reflective screen is made of a transparent material film, set at 45°, and composed of materials such as acrylic or thin glass sheets.

1.1. Research purposes

The imaging quality of holographic projection is influenced by the surrounding environment. Influencing factors such as the intensity of ambient lighting, background lighting conditions, and background color tones can affect the visual quality of the images on the reflective screen. Therefore, this research primarily investigates the impact of these external environmental variables on the image quality of holographic projection. Taking into consideration the points mentioned above, this research project sets the following objectives:

1. Investigate the influence of varying external lighting conditions and light colors on the different image qualities of holographic projection.
2. Compare the differences in visual image quality on the reflective screen under different background colors, and understand the quantitative changes in the image qualities.
3. Provide reference for image presentation quality control when setting up holographic projection performances.

1.2. Research scope and limitations

Reflective screen devices used in holographic projection can have imaging types ranging from four sides to one side. The more faces, the more complex the interaction between them will be. This study is only one part of the overall research plan. In addition, in order to simplify the understanding of the impact of external environmental variables on image quality, the scope and limitations of this study are stated as follows:

1. This study conducts experimental tests on single-dimensional holographic projection only. Multi-dimensional projection methods are prone to interactive effects between imaging planes, making it difficult to manage variable control. Therefore, only single-sided is tested to control the influence of variables.
2. There are many environmental factors that affect holographic projection images. This research focuses only on three variable factors: background light intensity changes, white and yellow background light environmental conditions and background color changes. Other variables such as reflective screen material factors and setting angles, projection screen light source intensity, etc. will be investigated in other studies.
3. In order to effectively explore the environmental variable issues set at this time, the projection intensity of the projection screen is fixed and controlled. The color of the ambient light is also simplified to simulate artificial diffuse light sources and is controlled in two colors: white and yellow.

2. Literature review

A variety of literature relevant to holographic projection was examined; for the purposes of this research, three perspectives are distinguished, namely: the optical principles of holographic projection, visual image quality, and the image evaluation and analysis methods.

2.1. Optical principles of holographic projection

Holographic projection employs the optical principle of utilizing hidden images and reflecting them onto a screen. This allows these concealed images to appear on a reflective screen, creating a highly immersive visual experience for viewers from their vantage point. As a result, this projection generates a compelling illusion that seems to manifest in the physical space, blurring the lines between reality and illusion. The inception of holographic projection can be traced back to a demonstration conducted by John Henry Pepper at the Royal Polytechnic Institution in London in the mid-nineteenth century, where he utilized reflective projection [3].

In essence, holographic projection relies on optical principles and specific equipment to present the complete image information of objects on imaging devices. This projection technology enables viewers to perceive three-dimensional projections and objects with the naked eye, without the need for polarized glasses. This versatile technology finds applications in various exhibition activities [4]. The imaging process of holographic projection is based on the principles of geometric optical imaging. When an image source emits light in front of a planar mirror, according to the laws of reflection, the point where the extension of the reflected rays intersects with the mirror's perpendicular normal results in the formation of a virtual image at a symmetrical position on the mirror's surface [5]. This mirror reflection of a virtual image is the optical principle employed in holographic projection visual imaging.

Furthermore, according to the principal laws of optics, when a light ray travels between two different mediums, a portion of the light ray is reflected back at the interface of the two mediums, which is referred to as the reflected light ray. Another portion of the light ray passes through the interface and enters the second medium. Due to the different material, the speed of light propagation also changes, resulting in an alteration of the angle of incidence of the light ray, known as the refraction of light [6].

Holographic projection technology has developed into 3D projection. Many industries are also trying to apply 3DHT (3D Hologram Technology). Experts are also actively developing advanced technologies to allow more industries to benefit from technology applications [7]. Holographic projection technology has also been fully used in other sectors, bringing people a new visual experience. It provides an interactive experience and can convey messages to users. Holographic projections have been identified as possessing considerable development potential in the field of smart exhibitions of the future [8]. Through the analysis of algorithms and production processes, diverse applications of holographic projection in various fields can be expected in the near future [9].

It can be found from the literature that holographic projection research in recent years has focused on technical aspects and industrial application issues. There has been little in-depth analysis and discussion of holographic image quality and influencing factors. Thus, this study investigates and discusses basic image quality and affecting factors to deepen understanding of these aspects, which sets it apart from other studies.

2.2. Visual image quality

Numerous factors influence the quality of visual images. Johnson [10] highlighted the need to consider complex spatial environmental stimuli when assessing image quality, as it is the result of multiple image-influencing factors. These factors include image color, sharpness, contrast, and the composition of image particles [10]. A study based on image contrast, saturation, and sharpness, which are influenced by the image's color and physical properties, found that people's perception of image quality is relatively better in high-contrast images compared to low-contrast ones. Similarly, images with high saturation exhibited relatively better perceived quality than those with low saturation [11].

There are two distinct approaches to assess image quality in photography. One is an objective evaluation based on scientific methods and tools, involving the systematic measurement and analysis of image characteristics. The other approach is more subjective, relying on the visual perception of observers as the basis for analysis. Overall, the quality of an image is objectively affected by four influencing factors: tone, edge detail, noise, and color [12].

Fu et al. [13] conducted a study analyzing the relationship between viewers' visual depth perception and the clarity of 3D imagery in the exhibition space of a lightweight field. Through simulated testing and adjustments, they refined the calculation formula for visual perspective and viewing depth. Kuo et al. [14] delved into the assessment of consumer psychological emotions concerning product shape and color in their paper. Their study involved physical observations and empirical testing of product features and colors to comprehend the impact of product styling and color tones. In 2024 Chan's study, the material color and surface film treatment of the reflective screen for holographic projection indeed had a certain degree of impact on image quality [15].

2.3. Image evaluation and analysis methods

The evaluation of image quality is typically conducted through both subjective and objective methods. Subjective assessment is generally influenced by the tester's personal preferences. On the other hand, objective assessment is carried out through computational methods. Common criteria for evaluating image quality include factors such as resolution, noise, color reproduction, contrast, and sharpness [16, 17]. In 2020, Tanaka et al. [18] studied the high-level contrast effect in judging the overall appearance of an object. They analyzed the glossiness and surface roughness of the appearance through experimental research methods.

As this research involves experimental methods in which the impact on formed images is captured through photography and subsequently analyzed for evaluation, it is more suitable to employ objective computer algorithms for assessment. There are numerous image analysis software options available in the market. The following subsections provide explanations of commonly used analysis software.

1. ImageJ software

   ImageJ is an image processing software primarily used for color analysis. Developed by the National Institutes of Health in the United States, it is a free and open-source image processing software. Image J finds significant applications in color analysis for medical, engineering, and mechanical engineering-related images [19].

2. Image Engineering software

   The Image Engineering image quality analysis software from Germany is designed for camera image analysis. The software comes with multiple built-in test modules, making image analysis more efficient and convenient. Its user-friendly interface is designed with a focus on user convenience [20].

3. OpenCV software,

   OpenCV, or the Open Source Computer Vision Library, was developed through an internal research project at Intel. It is used for image recognition, processing, and applications. OpenCV offers an extensive range of built-in image processing functions, and obtain the calculated analysis data for subsequent quantitative analysis and comparison [21]. In fact, OpenCV facilitates quantitative analysis of images, including color recognition and image segmentation [22]. As this software's functionality is well-suited for the execution of this research, it is the one selected for image evaluation.

Tsai and Kuan [11] mentioned that Johnson [10] considered sharpness, color saturation, and contrast to be key factors in judging image quality. Drawing upon discussions in related studies, this research project also delves into aspects of contrast, saturation, and sharpness concerning color and image physical properties to perform image quality analysis. Moreover, Yang [17] mentioned the definitions of various aspects of image quality. Contrast refers to the representation of tonal variation in the image. Lower contrast indicates a poorer tonal range, making it difficult for viewers to discern complete details.

3. Research methodology

Holographic projection comprises various presentation modes. However, this research focused on simplifying the investigation of the impact from external environmental factors on image formation. Thus, the experimental approach chosen for this study centers on single-sided holographic projection. The research was conducted through a series of tests, employing an experimental method [23] as described below. Digital camera images were captured and these images subsequently input into a computer for image quality analysis using the OpenCV image analysis software. For each image capture, only one variable was altered among the factors under investigation.

3.1. Experimental tools and setup

To investigate the impact of external environmental factors on image quality, an experimental chamber measuring 40cm in width, 36cm in height, and 30cm in depth was set up for this project. To prevent the influence of internal color reflections on image quality, the interior of the chamber predominantly featured a matte black background. The reflecting surface was made of a 2mm-thick transparent acrylic panel, which serves as the reflective projection screen. In addition to the aforementioned experimental chamber used in the main experiments, other equipment included a Microsoft Surface 14" tablet, used as the image projection screen, with screen brightness adjusted to 100

3.2. Experimental test variables

Two different color temperatures of common ambient light sources were simulated in the surrounding environment, such as warm yellow and cool white light. Furthermore, tests were conducted to examine the impact of variations in ambient light intensity under different illuminance levels. Investigations were also carried out to evaluate the imaging quality under different background colors situations. Finally, experiments were conducted to assess the effects of changing the projection screen to reflection screen distance on the imaging quality. In summary, the environmental factors defined for exploration in this study include the following variable items:

1. Effect of external background light source color (white light / 6500°K; yellow light / 3000°K).
2. Variations in ambient light source intensity (under white and yellow diffuse light / 50, 100, 300, 500, 1000 lux).
3. Changes in environmental background color (white, gray, and black).

3.3. Experimental operation

The experiment was conducted in a single experimental space. In addition to the single-sided projection experimental chamber, external environmental lighting sources were controlled using LED ring lights. The position of the light intensity was measured on front of the reflection screen. Once all the pieces of experimental equipment were positioned and fixed, they were not moved. Except for the controlled LED light sources required for the experiment, all other light sources, both inside and outside the chamber were excluded, so there was no interference to the experiment from external light sources. In order to maintain the consistency of the experimental environment, testing of each experimental variable was completed within the same time period. Thus, the experimental consistency was completely under control. Each image was consistently captured from the same fixed position and size, and image quality analysis calculations were performed using the OpenCV image quality analysis software. The research operational procedures are outlined in Fig. 1.

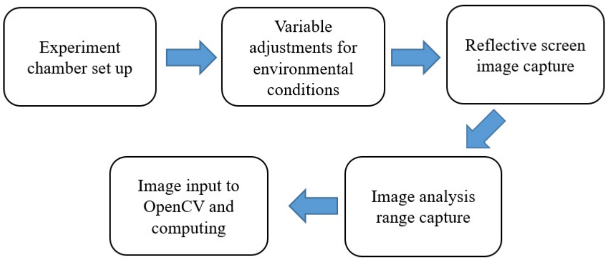


Fig. 1. Experimental operation flow chart.

3.4. Image quality analysis contents

After referencing relevant literature on image quality analysis content and methods, the primary aspects of image quality investigated in this research were set as follows:

1. Composition of average color R/G/B - Analyzing changes in the composition of the three primary colors of the average color (Numeric range: 0 to 255).
2. Contrast changes - Comparing differences in high and low contrast in the representation of image tonalities (range: 0 to 127.5).
3. Variations in sharpness - Analyzing changes in image clarity (range: 0 to 127.5).
4. Changes in saturation - Understanding alterations in color purity or vibrancy (range: 0 to 255).

This research uses the OpenCV image calculation program to analyze image quality, which is an evaluation method that is different from the subjective judgment of viewers. Changes in image quality can be clearly presented as quantitative data, and researchers can detect subtle differences in image quality, which cannot be achieved by human eyesight. Moreover, through the calculation and analysis data of the image program, the precise values of the image quality of holographic projection under variable conditions can be revealed. Hence, the performance effect of holographic projection can be more effectively controlled, providing viewers with a better visual experience.

4. Data analysis and results

The images captured on the reflective screen were saved and processed using the OpenCV image analysis program for calculation. The analysis involved computing the numerical values of average color (R/G/B) for each image, as well as contrast, sharpness, and saturation. Subsequent quantitative comparisons of each value were carried out.

4.1. Impact of external lighting conditions

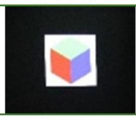
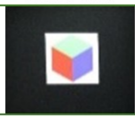
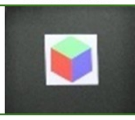
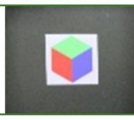
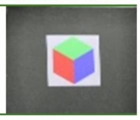
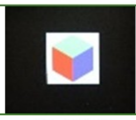
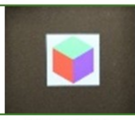
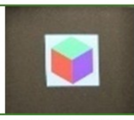
Experiments were conducted under two different diffuse external lighting conditions, white light and yellow light. These conditions were tested at five different levels of illuminance, with illuminance intensities of 50, 100, 300, 500, and 1000 lux (Lx). The captured images and computer analysis results are summarized in Table 1.

From the analysis results, it is evident that, regardless of whether in a white light or yellow light environment, with increasing illuminance, there was a noticeable increase in the average color values of the three primary colors, R/G/B, in the imaged patterns. However, in the case of white light, the average color values of R/G/B become noticeably less variable and approach a stable state situation when the illuminance of diffused light reaches 500 lux or higher. Conversely, under yellow light condition, the values of the average color R/G/B continued to increase with the red (R) value being significantly higher than for white light when reaching 1000 lux, while there were no substantial differences between the green (G) and blue (B) values. This indicates that, as illuminance increases, the rendering effect of yellow light on images becomes more pronounced than that of white light.

In fact, upon initial visual observation of pattern changes directly, it was found that, under yellow light rendering, the blue portions of the images exhibited a slight shift towards purple, while the pattern changes under white light were not as pronounced. In fact, when the illumination exceeded 500Lx under white light, there was no significant difference in the image quality content of the four evaluations. It is evident that regardless of whether white light or yellow light, under high illumination, the overall imaging state on the holographic projection reflective screen is adversely affected by the external high-intensity ambient light. Consequently, the overall imaging effect becomes highly undesirable under such circumstances.

Regarding contrast variations, as shown in Table 1, the data indicate that the images displayed on the reflective screen under ambient illuminance by both white light and yellow light did not exhibit any significant difference. As the external environmental illuminance increased, the contrast of the images tended to decrease, signifying a trend towards subdued colors and, consequently, a less favorable visual effect for viewers. This also illustrates that,

Table 1. Image quality analysis and calculation results under different illuminance

Color	Illuminance	50 Lux	100 Lux	300 Lux	500 Lux	1000 Lux
White 6500K	Image					
	R/G/B	58/56/59	70/69/71	94/96/95	112/113/111	113/113/111
	Contrast	78	72	56	47	43
	Sharpness	141	120	138	153	167
	Saturation	45	37	27	25	25
Yellow 3000K	Image					
	R/G/B	61/58/58	85/78/72	106/97/90	112/104/96	132/119/105
	Contrast	77	68	56	51	42
	Sharpness	104	95	112	147	163
	Saturation	46	59	67	70	80

in holographic projection, the surrounding environment should ideally be darker to achieve higher image contrast, richer and more vivid image presentation, and an overall improved display effect.

As for the analysis results of sharpness, under the influence of different color temperature ambient light sources, white light exhibited relatively stable variations in sharpness at different illuminance levels, presenting no differences between low and high illuminance levels. However, in a yellow light environment, sharpness tended to increase with higher illuminance values. Nevertheless, when the illuminance reached 500 lux or higher, the sharpness values of white light and yellow light tended to converge with the differences between them becoming less pronounced. Fig. 2 shows the quantitative trend changes in image contrast, sharpness and saturation under different illumination conditions. Quantitative data permits clearer observations of changes in these image qualities.

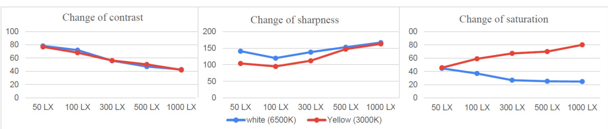


Fig. 2. Trend changes in contrast, sharpness and saturation under different illuminance.

It is shown that under external lighting conditions of white light and yellow light, holographic projection images exhibited distinct differences in regard to color saturation. Under white light, as the external illuminance value increased, the saturation of colors tended to decrease. However, in situations exceeding 100 lux, the saturation stabilized at a low value, indicating that higher illuminance levels in a white light environment led to less desirable color saturation. Therefore, a high illuminance white light environment is not considered an ideal setting for holographic projection. Conversely, under yellow light ambient conditions, as the illuminance value increased, color saturation significantly improved, exhibiting a pattern opposite to that of white light. Clearly, in a yellow light environment, the performance of color saturation in holographic projection images is notably superior to that in a white light environment.

Trend changes in the statistical charts in Fig. 2 show that contrast decreases as the ambient illumination increases. The reason is that when the illumination is stronger, the image becomes more gray-scale, so its contrast value decreases. When calculating sharpness, color will be converted into pixel grayscale first, and then go through a second-order differential derivation operation. Under the condition of 100 lux, the value may be reduced when converted into grayscale, resulting in a reduction in sharpness. Saturation is obviously very different for white light and yellow light. When the white light is stronger, color vividness decreases, so saturation tends to decrease as well.

4.2. Impact of background color changes

In general, a full darker background environment is preferred for optimal effects in holographic projection displays. In this part of the experimental testing, we attempted to explore the impact of background color on image quality under three variable conditions: white, gray, and black backgrounds in a yellow diffuse light environment.

Regarding variations in the composition of average color

(R/G/B), as shown in Table 2, under a white background, the numerical values of average color R/G/B were relatively lower at 50 lux compared to other illuminance levels. However, as illuminance exceeded 100 lux, the values tended to be similar, with minimal differences up to 1000 lux. Under a gray background, at 50 lux and 100 lux, the relative numerical values of average color R/G/B were lower, but beyond 300 lux, the values approached a stable state with minimal differences compared to the white background. However, under a black background, the average R/G/B values showed an increasing trend with increasing illuminance. It is evident that when the background colors are white and gray, as long as the illuminance exceeds 100 lux, the overall average color R/G/B remains relatively stable. This implies that the average color of the images is maintained with a consistent color tone and minimal variations in color quality. It was evident that the color visual effects of images against a black background were notably superior to those on white and gray backgrounds.

Indeed, when directly observing the variation in imaging patterns under different illuminations for each background color as depicted in Table 2, it is noticeable that the overall visual effect of the white background patterns, regardless of the illumination level, appeared as if a layer of haze is present in the imagery. This less-than-ideal visual effect may be attributed to the higher surface reflectance of the white background. When the light source is projected onto the reflective screen, a portion of the light is reflected in multiple directions. With the background color being white, this reflected light bounces back onto the reflective screen, causing interference with the imaging of the reflective screen and consequently impacting the quality of viewing.

Under a gray background, clearer pattern states were observed only at a low illumination level of 50 Lx. Meanwhile, under a black background, the images at both 50 Lx and 100 Lx illumination levels appeared to be clearer visually. From this, a conclusion can be drawn that the imaging effect in holographic projection is significantly influenced by the background color, and this influence becomes more pronounced with higher external background illumination. Therefore, in holographic projection facilities, a darker background environment tends to yield better imaging effects.

According to the variations in image quality contrast under different background conditions, it can be observed that, under various illuminance conditions, black backgrounds exhibited considerably better contrast values compared to gray and white backgrounds and gray outperforms white. Furthermore, from the statistical data, it is

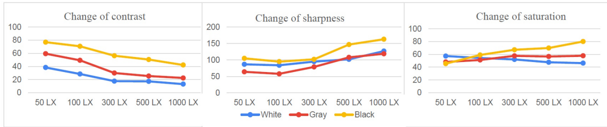


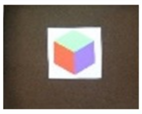
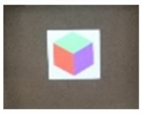
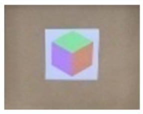
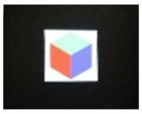
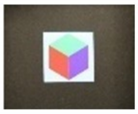
Fig. 3. Trend changes in contrast, sharpness and saturation under different background colors.

evident that, as the external environmental illuminance intensity increased, the contrast of image quality tends to decrease. This observation aligns with the common understanding that holographic projection typically performs better in darker environments.

In Table 2, sharpness values depicted that white backgrounds exhibited a relatively smooth variation in sharpness values under various illuminance conditions with changes being less pronounced. Conversely, black and gray backgrounds showed more distinct variations; after illuminance surpassed 100 lux, the sharpness values of the images exhibited a more noticeable increase. Overall, in brighter environments, it seems that image sharpness was better with a black background compared to a white background. At illuminance levels of 500 lux and 1000 lux, the sharpness values for white and gray backgrounds tended to converge, indicating that, when the external environmental illuminance exceeded a certain threshold, the differences in image quality between white and gray backgrounds become less pronounced.

In terms of saturation variation, when the illuminance was 50 lux, the saturation values for gray and black backgrounds was similar. It seems that, at this point, the ambient lighting was relatively dim and its overall impact on the visual image was not significant. In an environment with a white background, the saturation values decreased with increasing illuminance, especially under high illuminance conditions. However, in the case of gray and black backgrounds, there was a trend of increasing saturation values, particularly with a black background, where increasing illuminance led to higher saturation values. Another observed phenomenon was that, in the presence of a gray background, the saturation values tended to exhibit a smoother variation when the ambient illuminance exceeded 300 lux with minimal fluctuations. This suggests that increasing illuminance has a less pronounced impact on saturation in the gray background condition. Based on the trends of saturation values in Table 2, it can be inferred that, against a black background, saturation values increase as ambient illuminance becomes stronger. Conversely, with lighter background colors, the influence of increasing ambient illuminance on image saturation tends to be less pronounced.

Table 2. Image quality calculation results against different background colors.

BG Color	Illuminance	50 Lux	100 Lux	300 Lux	500 Lux	1000 Lux
White	Image					
	R/G/B	152/137/128	174/152/136	174/161/150	176/163/150	172/153/134
	Contrast	38	29	18	17	13
	Sharpness	87	84	95	102	127
	Saturation	57	54	52	48	46
Gray	Image					
	R/G/B	110/96/86	126/118/112	158/146/136	162/154/153	156/146/138
	Contrast	60	49	30	25	22
	Sharpness	64	58	79	108	119
	Saturation	48	51	58	57	58
Black	Image					
	R/G/B	61/58/58	85/78/72	106/97/90	112/104/96	131/119/105
	Contrast	77	68	56	51	42
	Sharpness	104	95	102	147	163
	Saturation	46	59	67	70	80

In the case of a white background, increasing ambient illuminance leads to a decrease in saturation. Fig. 3 shows the trend changes in contrast, sharpness and saturation of image quality data under different background colors and illumination conditions, which more clearly illustrates the impact of different color backgrounds.

The changes in image contrast, sharpness and saturation of holographic projected images under different background colors are similar to the results in the above section. The contrast decreases as the illumination of the environment increases, and the sharpness tends to be lower at 100 lux. Saturation experiences the worst effect in white light, for the reasons mentioned in the previous section. Overall, the image quality of holographic projection is the best when the ambient color is black.

5. Conclusions and suggestions

This study conducted holographic projection experiments using single-sided projection, primarily due to its superior control over variables. Building upon the experiments and analysis of single-sided holographic projection presented in this paper, several conclusions can be drawn:

1. Under different color temperatures of ambient lighting, the average R/G/B color values of the image exhibit relatively minor variations, regardless of whether the lighting is white or yellow. However, as the illuminance increases, the average R/G/B values also increase. In terms of image contrast, there is no significant difference in the impact of white or yellow lighting on image contrast, whereas increasing illuminance tends to decrease image contrast. As for image sharpness, white lighting outperforms yellow lighting at lower illuminance levels but the differences between the two become less pronounced at higher illuminance levels. Regarding image saturation, white and yellow lighting exhibit opposite trends. As illuminance increases, the saturation under yellow lighting tends to rise, while white lighting shows a decreasing satura-

tion trend.

2. Against different background colors, the overall average R/G/B color values follow the pattern of white background > gray background > black background. Black background provides superior contrast for image quality; however, as ambient illuminance increases, the contrast values for all three background colors tend to decrease. Regarding image sharpness, all three background colors show improvements as ambient illuminance increases. At lower illuminance levels, black backgrounds outperform white backgrounds, with gray backgrounds having the lowest values. However, at higher ambient illuminance levels, the values for white and gray backgrounds tend to approach each other. As for saturation, the saturation values for black and gray backgrounds increase slightly with increasing illuminance.

The results provide a feasible scientific and objective form of analysis for imaging researchers, making a substantial and enlightening contribution to the analysis and evaluation of image quality. In the practice of holographic projection, through the analysis results of image quality calculation, one can observe the quantitative and substantial changes of each image quality item under external environmental variables, which will provide effective images quality control reference to help designers of future holographic projection exhibition activities, and also provide viewers with a better visual experience. It will make a certain degree of contribution to improving the quality of future projection displays.

5.1. Future research recommendations

Many factors can influence the quality of holographic projection images. This study only focused on experiments and analysis involving external environmental conditions. However, it is essential to acknowledge that there are other intrinsic or material variables affecting the imaging quality of the reflective screen. Therefore, future research in this area could explore inter-screen angles, as well as reflective screen thickness and application of colored films. In this study, experiments were conducted with a fixed 45° angle for the projection screen and the reflective screen. Investigating how changes in the angle of the projection screen impact image quality is a topic that is worth further exploration.

With the popularity of holographic projection displays on the rise, there are various avenues for research in this field. It is hoped that this study will contribute to the foundational research in this field and provide more efficient references for setting up holographic projection systems in the future. In the ever evolving and innovative field of display technology, it is also hoped that more researchers will engage in fundamental research on projection technology, leading to a brighter future for this exhibition field.

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