Two-Fold Color Compensation Algorithm Operation for Optical See-Through Head Mounted Display

Hyeonseok Eo[1], Sungeun Park[1], Wooksung Kim[1]

wsungkim@postech.ac.kr
[1]Dept. Electrical Engineering, POSTECH, Pohang, Gyeongbuk, 37673, Korea
Keywords: Optical see-through, head mounted display, color compensation, augmented reality

ABSTRACT

This paper presents the improvement of color usability of optical see-through head mounted displays (OST-HMDs). As a solution to the black and color distortion, we proposed a new color compensation method adding a secondary display to OST-HMDs. The compensation results showed a compensation ratio of 99.26 %.

1 Introduction

Optical see-through head mounted displays (OST-HMDs) are used to impose virtual images on a true scene. However, these virtual images can seem unnatural in some circumstances. The main limitations of OST-HMDs' naturalness are black color expression and image distortion [1-3]. Existing OST-HMDs cannot express black because they make virtual images with projected red, green, blue lights from micro-display and do not have any back plates which can blind the projected lights for black color. A secondary display has been added to OST-HMDs to achieve active and pixel-wise back plate while maintaining the optical see-through property.

Image feedback compensation has been introduced as a solution for the image distortion [4]. This method compensates virtual images by distorting the original virtual images according to adjacent environments. However, this method has limitations due to constraints on OST-HMDs' operational ranges.

Here, we propose a two-fold color compensation algorithm to solve the two main disadvantages of OST-HMDs. In the algorithm, the secondary display and image-feedback compensation work complementary. The secondary display performs both an active back plate and a color filter that can overcome the limitation of the image feedback compensation. The display adjusts the ambient noise factors to output clear virtual images with the image feedback compensation while maximally guaranteeing optical see-through characteristics.

2 Experiment

2.1 Algorithm

The two-fold compensation algorithm consists of two algorithm modules: 2nd display and AR image feedback distortion. To implement each module, we measured wavelength transmission characteristics according to the driving change of the 2nd display and spectrum data for each Red, Green, Blue (RGB) gray scale of the OST-HMD (MOVERIO BT-300, EPSON).

The 2nd display compensation algorithm reduces the ambient light intensity so that the next compensation module can effectively correct colors. We designed the 2nd display module to the 2nd display driving condition that may have the highest transmittance. The next compensation algorithm module intentionally distorts the AR images from the reference images so that it can almost become the reference images when the AR images are mixed with the ambient lights reduced by the previous module. We measured the similarity of the compensated image to the reference image by comparing the coordinate values of each image's CIE L*a*b* and defined the compensation rate by using the CIE L*a*b* coordinates values of the distorted image and the reference image. In the two-fold compensation algorithm, 2nd display operated as one-mixed color shutter and AR displayed various colored images.

2.2 Experimental setup

All experiments were conducted in a dark room and room temperature environment. Ambient light from the ambient light generator (MS610, BenQ) was reflected by the reflector and passed through the 2nd display. The distance that ambient light travel from the generator to the spectrometer (GL SPECTIS 1.0 Touch+ Flicker, GL Optics) which was located on the rear of the AR device was set to 40 cm, in which the illuminance variations can be measured up to 40,000 lx. The 2nd display was located 3 cm in front of the AR device, and the spectrometer was located 3 cm behind the AR device. The light sensor which consisted of RGB photodiodes was located at the top of the AR device and measured ambient lights which did not pass through the 2nd display. The images used for ambient lights and AR are monochrome images that have RGB gray scale values of 0 to 255.

2.3 2nd display compensation algorithm

Wavelength spectrum values which changed from a white ambient light by passing through the 2nd display were measured by spectrometer, and we determined the wavelength transmission characteristics, contrast ratio, and maximum and minimum transmittances of the 2nd display with those wavelength spectrum values. We set the effective range of the wavelength transmission characteristics as the values did not change abruptly and remained certain constant value.

The 2nd display compensation algorithm uses the ambient light values which are measured by the light sensor as input data. This input data is reprocessed into spectrum data using the color matching function. The algorithm predicts the change of ambient lights passing through the 2nd display as the product of the reprocessed spectrum data and the wavelength transmission characteristics, and at this time, the algorithm operates to present the driving condition with the highest transmittance as an output. Then, the predicted values are used in the experiment to measure the compensation accuracy.

2.4 Image feedback compensation algorithm

Spectrum data for each RGB gray scale of the AR device were measured in a dark room without 2nd display or ambient lights. XYZ tristimulus values were calculated using the color matching function from the spectrum data. The CIE L*a*b* coordinate values of the images compensated by the 2nd display module must be in a boundary generated by the tristimulus vales. The image feedback compensation algorithm determines whether the images' coordinates compensated by the previous module are within the boundary. If compensation is possible, the algorithm presents the feedback degree of the AR images as an output by comparing the compensated image coordinate with the reference image's coordinate.

3 Results

We evaluated the two-fold compensation algorithm. (Table I). When ambient light (X: 260.2, Y: 144.7, Z: 11.3) distorted the reference AR image, the algorithm compensated for the distorted image theoretically. The CIE L*a*b* was used for the algorithm's color-expression coordinates because it can compensate for both light intensity and color. The error values were calculated assuming that the OLED's light-intensity error was corrected. The algorithm determined the highest 2nd display operation condition (R: 130, G: 130, B: 130) which manipulated the ambient light to set the distorted AR image's coordinates within the AR operation limit, and the 2nd display transmittance showed 5.14 % at the operation condition. AR image's condition slightly changed from (R: 200, G: 100, B: 100) to (R: 198, G: 100, B: 100) for detailed color compensation. The operation difference was not large, and therefore it confirmed that the algorithm operated as designed, and could get a compensation of ratio 98.81 %.

To verify the reliability of the algorithm, we operated it in an extreme ambient light environment (X: 10,887, Y: 9,418, Z: 16,932) for the same reference AR image (Table II). The compensation results showed a maximum error of 5.61 %, and a compensation ratio 99.26 %. These results show that the algorithm works well in various ambient-light environments. Moreover, we evaluated the algorithm with various colors in a specific ambient light environment by operating the algorithm multiple times at the same time (Fig. 2).

TABLE I
TWO-FOLD COMPENSATION ALGORITHM RESULT WITH AN AMBIENT LIGHT (X: 260.2, Y: 144.7, Z: 11.3)

Compensation Result				
	Reference AR image	Distortion	Compensation	Error (%)
L*	54.27	62.20	54.35	0.15
a*	16.21	33.10	15.98	1.42
b*	30.09	41.97	30.19	0.33
Compensation ratio (%)		98.81		
Algorithm Output				
		R	G	B
2nd display		130	130	130
AR image		198	100	100
2nd display Transmittance (%)		5.14		

TABLE II
TWO-FOLD COMPENSATION ALGORITHM RESULT WITH AN AMBIENT LIGHT (X: 10,887, Y: 0,418, Z: 16,932)

Compensation Result				
	Referen ce AR image	Distortio n	Compensatio n	Erro r (%)
L *	54.27	191.20	54.44	0.31
a*	16.21	33.63	15.30	5.61
b*	30.09	-52.70	30.85	2.53
Compensation ratio (%)		99.26		
Algorithm Output				
		R	G	B
2nd display		130	105	33
AR image		88	3	38
2nd display Transmittance (%)		3.77		

4 Discussion

The algorithm showed > 98% compensation ratio in evaluation experiments. The highly compensable algorithm can be used for pre-compensation method about ambient light. However, the algorithm's operation time was several tens of seconds. This lag is not suitable for a real-time compensation system. The reasons for the slow operation are the large volume of the 2nd display spectral data and AR spectral data. Therefore, we will optimize the algorithm data volume and numerical method. We consider deep learning as a candidate to replace the calculation method. We will also work on a partial-occlusion control system with the color-compensation algorithm.

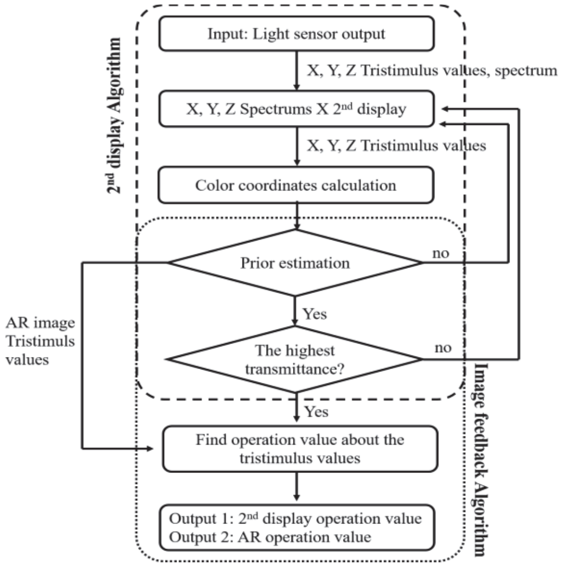

Fig. 1 The two-fold compensation algorithm flow.

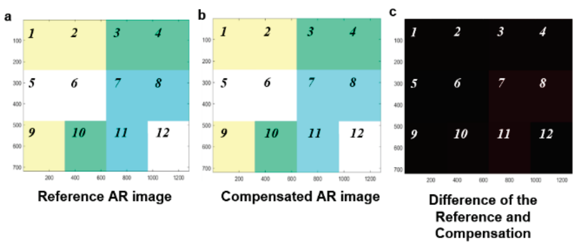

Fig. 2 Various colored image compensation result.

5 Conclusions

The main limitations of OST-HMDs are black color expression and image distortion. To improve the naturalness of virtual images of OST-HMDs, we proposed a two-fold compensation algorithm with a secondary display and the image feedback method (Fig. 1). The algorithm showed > 98% compensation ratio and several tens of seconds operational speed. The low speed is need to improve. If the algorithm speed is improved in our follow-up study, we will expect that a real-time algorithm will make a great contribution to expressing virtual images that are difficult to distinguish from real environments.

References

[1] J. P. Rolland, & H. Hua, "Head-mounted display systems." Encyclopedia of optical engineering, 2. 2005.

[2] A. Wilson, & H. Hua, "Design and prototype of an augmented reality display with per-pixel mutual occlusion capability." Optics express, 25(24), 30539-30549 2017

[3] K. Kiyokawa, Y. Kuratea, & H. Ohno, "An optical see-through display for mutual occlusion with a real-time stereovision system." Computer & Graphics, 25(5), 765-779. 2001.

[4] Y. Zhang, R. Wang, E. Y., W. Hua, & H. Bao, "Color Contrast Enhanced Rendering for Optical See-through Head-mounted Displays." IEEE Transaction on Visualization and Computer Graphics. 2021