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LCD 디스플레이용 색채계 렌즈에 관한 비결상 광학설계

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본 논문에서는 LCD 디스플레이용 색채계 렌즈에 관해 근축광학적인 방법에 의한 비결상 광학설계를 소개한다. 색채계란 디스플레이 상의 측정영역으로부터 방출된 광을 빛의 3원색인 빨강, 녹색, 초록으로 분해하는 측정기기로써, 결상렌즈가 아닌 집광렌즈를 필요로 한다. 집광렌즈는 비결상 렌즈이고 측정영역과 감지영역 간의 특정한 압축비 조건을 만족해야 한다. 총체적인 비결상 광학조건을 이해하기 위해, 근축광학을 사용하여 필요충분조건을 해석적인 표현식으로 유도하였고, 나아가 간단한 공식으로 발전시켰다. 이 공식의 타당성은 CODE V와 Light-Tools를 사용하여 검증하였다. 이 공식은 색채계용 집광렌즈 뿐만 아니라, 레이저 빔의 세기를 균일하게 만들기 위한 어레이 렌즈의 설계에도 유용하게 확장 적용될 수 있다.

Non-imaging Optical Design of a Measurement Probe for LCD Display Used in a Color Analyzer

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We introduce Gaussian (or paraxial) optics that can be successfully applied to design, for use in a color analyzer, a non-imaging optical system on a measurement probe for LCD display. The color analyzer is used to decompose colored lights leaving from some measurement area on the LCD display to red, green, and blue. The color analyzer must include a condenser lens whose purpose is to gather colored lights to illuminate a small area on the sensor. In order to satisfy a reduction ratio between the measurement area and the sensing area with a non-imaging condition, a condenser lens is analytically treated by means of Gaussian optics so that good understanding of the non-imaging condenser lens is achieved as a good design is derived. As a result, the technique shows the necessity of analytical treatment in contrast to the design approach using only commercial software such as CODE-V, Light-Tools, and others. Of course, CODE V and Light-Tools are also utilized in this paper to confirm and complete the Gaussian optical design.

Keywords: Color analyzer, Non-imaging optical design, Gaussian optics, Paraxial optical design
OCIS codes: (220.3620) Lens system design; (080.2740) Geometric optical design; (080.4298) Nonimaging optics; (330.1710) Color, measurement

I. INTRODUCTION

Flat panel display is the one of axes supporting Korean economy with semiconductor, which means different types of displays such as liquid crystal display, plasma display panel and active matrix organic light emitting diode. They are essentially utilized in our everyday life used in computer monitor, television, and mobile applications. In addition to having a meaning as living necessities, they have a great riffle effect on surrounding industries which are related to manufacturing equipments, inspection technologies, and chemical products, etc. When it comes to inspection technologies especially in color analyzer, it is mostly occupied by Konica Minolta Sensing, Inc [1] in terms of a market share. These studies are able to provide an

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Color versions of one or more of the figures in this paper are available online.

optical solution to design and develop color analyzers in Korean inspection industries.

It is necessary to discuss about what color is in flat panel display. When we see the light leaving from flat panel display, colors are sensed by cone cells in the retina of the eye, which ranges from violet light with a wavelength of 0.4 μm to red light with a wavelength of 0.76 μm [2]. When the distribution of light energy is not effectively uniform across the spectral range, the light appears colored. Some typical frequency (or wavelength) distributions can be seen to be colors which would be perceived as red, green, and blue light. And a wide range of colors could be produced by mixing three colored lights as long as their frequencies were widely separated. When three such lights are able to produce white light, they are called primary colors. There is no single unique set of these primary colors [3]. Since a wide range of various colors can be generated by mixing red, green, and blue, these primaries are commonly used in the display colorimetry. The each pixel on flat panel display can separately emit red, green, and blue lights [4-5].

Color analyzer should decompose colored lights leaving from some measurement area on LCD display to each red, green, and blue light. In order to achieve this purpose, color analyzer needs optical design with non-imaging treatment for gathering and illuminating colored lights within a small area on the sensor [6-7]. While optical designs were mostly reported on imaging optical system [8-10], this study is willing to introduce how to design non-imaging optics by the analytical treatment using Gaussian (or paraxial) optics [11-13]. And then an obtained design from the analytical treatment is proceeded to be confirmed and completed by means of commercial software such as CODE V [14] and Light-Tools [15]. As a result, it is noticed that the design approach only with commercial software cannot offer the well understanding of non-imaging optical system as much as good designs are achieved. Hence, we expect that this research is helpful to design other non-imaging optical systems analytically based on Gaussian optics.

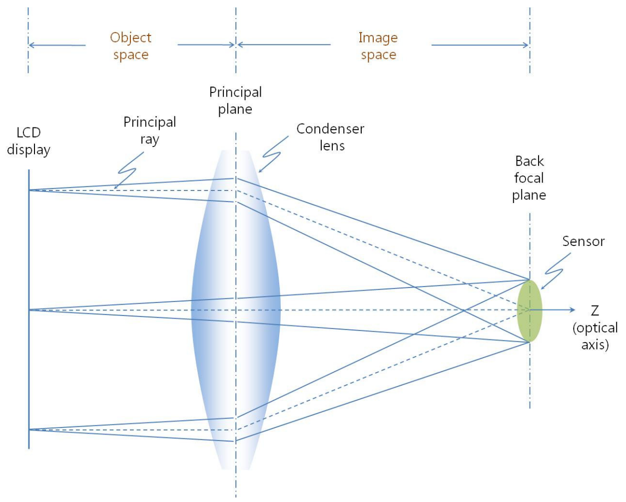

FIG. 3. Improved color analyzer which adopts non-imaging optical layout.

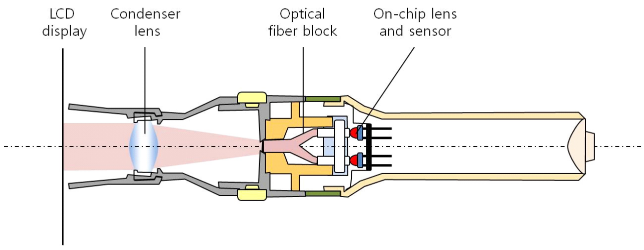

FIG. 4. Typical type of color analyzer in addition to optical fiber block.

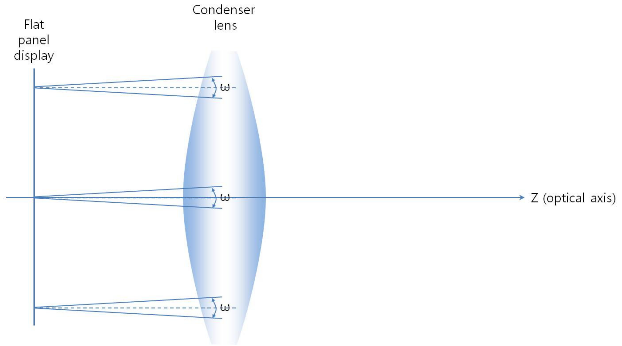

FIG. 1. According to IEC 61747-6, the viewing angle (ω) of the measuring instrument for evaluating LCD display should be within 5° or ±2.5°.

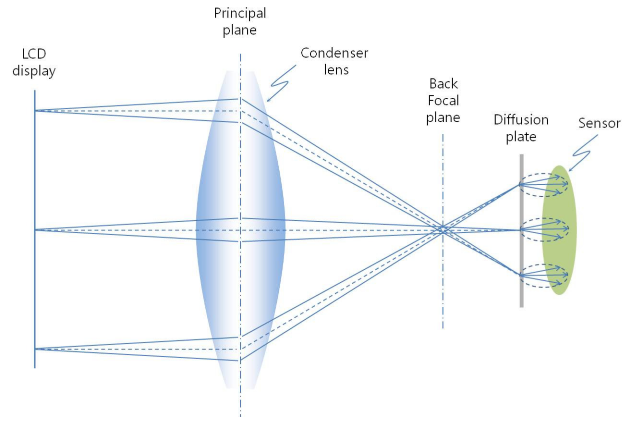

FIG. 2. Conventional color analyzer with diffusion plate.

II. SYSTEM LAYOUTS AND DESIGN REQUIRMENTS

Since flat panel display emits lights within a relatively narrow angle, it should be indispensably satisfied for color analyzer to have the same narrow viewing angle which causes to analyze the same chromaticity as perceived by a person. In this paper, we are going to proceed with LCD display among different kinds of displays to explain non-imaging optical design in detail. All the discussion described here is able to taken commonly to other displays. According to IEC (International Electrotechnical Commission) 61747-6 [16], the viewing angle (ω) of the measuring instrument for evaluating LCD display should be within 5° or ±2.5° as shown in Fig. 1.

The variation of luminance or chromaticity on the measurement area of LCD display influences the measured chromaticity value, which tends to make the value less credible. A diffusion plate is used to reduce this influence in color analyzer, as shown in Fig. 2. However, while a diffusion plate is able to make the measured value more credible, it also causes to reduce the sensitivity of color analyzer due to the even lower amount of light reaching the sensor [1]. Therefore, in terms of the illuminated uniformity and the amount of light on the sensing area, color analyzer needs non-imaging lens as a condenser lens instead of imaging lens, as shown in Fig. 3.

As shown in Fig. 3, colored lights leaving from the measurement area at each different point are illuminated on the sensor by a condenser lens with some reduction ratio between the measurement area and the sensing area, while colored lights are satisfied with the telecentric condition where each principal ray should be parallel to optical axis on object space [17]. This telecentric condition causes the sensor to be located on the back focal plane of a condenser lens, which is well known from the fundamental geometric optics. And the amount of light on LCD display is taken within φ27 mm (or the diameter of 27 mm) in the measurement area with the viewing angle of 5° or ±2.5° from the criterion of IEC 61747-6, as shown in Fig. 3.

The sensor in Fig. 3 can be replaced by the receiving window of optical block as shown in Fig. 4 [1]. Fig. 4 shows that the main components of color analyzer consist of condenser lens, optical fiber block, on-chip lenses, and sensor. The light beam leaving from the measurement area on LCD display is illuminated onto the receiving window of the optical fiber block. And then, the incident light is mixed inside the optical fiber block and split into 3 parts directed to red, green, and blue sensors on which the splitted lights are respectively focused by each on-chip lens.

III. NON-IMAGING OPTICAL DESIGN BY MEANS OF GAUSSIAN OPTICS

As shown in Fig. 3 and Fig. 4 of previous section II, a condenser lens should satisfy such a condition that the light with the viewing angle of ±2.5° leaving from the measurement area of φ27 mm on LCD display is illuminated onto the sensing area with a reduction ratio and the telecentric condition. Gaussian optics suggests that a ray tracing technique is taken for a condenser lens to find a design formula. It is well known that ray tracing equations from Gaussian optics are recursively expressed as following equations of Eq. (1) to Eq. (4) [11-12].

$$n_1'u_1' - n_1u_1 = k_1h_1 \tag{1}$$

$$n_2'u_2' - n_2u_2 = k_2h_2 \tag{2}$$

$$h_2 = h_1 - d_1u_1' \tag{3}$$

$$h_3 = h_2 - d_2u_2' \tag{4}$$

where Fig. 5 shows that the subscripts like 1, 2, and 3 are labeled the surface number, the prime symbol is the quantity after refraction, the slope angles are *u* and *u'*, the refractive indices are *n* and *n'*, the refracting powers at each surface are k_1 and k_2, the heights at each surface are h_1, h_2, and h_3, and the distances between surfaces are d_0, d_1 and d_2, respectively.

Successively, if the ray tracing is taken to a condenser lens of Fig. 5 for a (+) symbol ray, the heights at each surface are given to the following equations of Eq. (5) to (9).

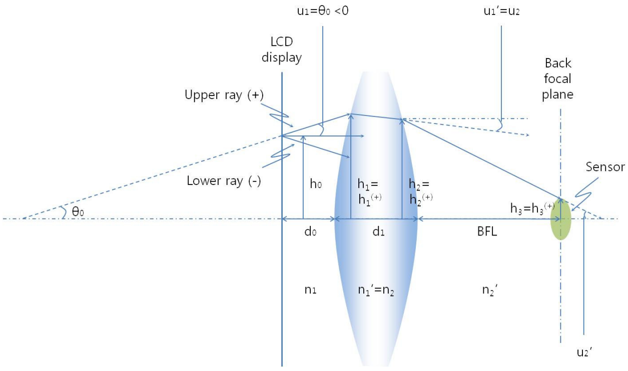

FIG. 5. The upper ray tracing symbolized by (+) using the recursion relationship as shown in Eq. (1) to (4). BFL: Back Focal Length.

$$h_1^{(+)} = h_0 + d_0\theta_0 \tag{5}$$

$$h_2^{(+)} = h_0 + d_0\theta_0 - \frac{(d_1\theta_0 + d_1k_1h_0 + d_0d_1k_1\theta_0)}{n} \tag{6}$$

$$h_3^{(+)} = h_2^{(+)} - \frac{1-(d_1k_1/n)}{K}(\theta_0 + k_1h_0 + k_2h_0 + d_0k_1\theta_0 + d_0k_2\theta_0 - hs_3^{(+)}) \tag{7}$$

$$hs_3^{(+)} = \frac{d_1k_2\theta_0 + d_1k_1k_2h_0 + d_0d_1k_1k_2\theta_0}{n} \tag{8}$$

$$K = k_1 + k_2 - \frac{d_1}{n}k_1k_2 \tag{9}$$

where the viewing angle of the upper ray is labeled θ_0 and the total refracting power of a condenser lens is K. And note that $d_0 < 0$ and $\theta_0 < 0$ from the sign convention [2]. In addition, if thin lens approximation is taken to Eq. (7), which causes to be $d_1 \approx 0$, then the height of upper ray symbolized by (+) can be simplified to Eq. (11).

$$h_3^{(+)} = h_0 + d_0\theta_0 - \frac{1}{K}\{\ \theta_0 + (k_1 + k_2)h_0 + (k_1 + k_2)d_0\theta_0\ \} \tag{10}$$

$$h_3^{(+)} = \left|\ \frac{\theta_0}{K}\ \right| \tag{11}$$

If we continue to trace the lower ray symbolized by (-) in Fig. 6, the resultant equation can be simplified as the following equation of Eq. (13) with the sign convention of $d_0 < 0$ and $\varphi_0 > 0$. And finally, the diameter (D) of the illuminated area on the sensor is given to 2 times as wide as Eq. (13).

$$h_1^{(-)} = h_0 + d_0\varphi_0 \tag{12}$$

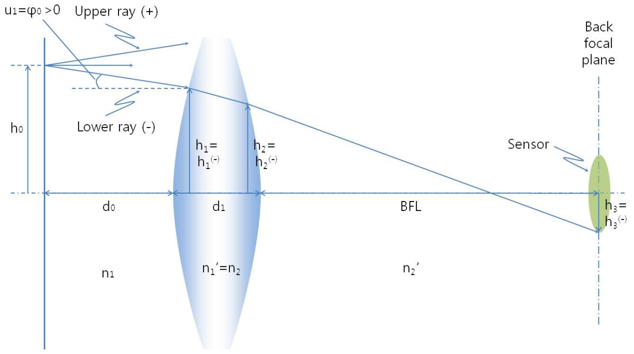

FIG. 6. The lower ray tracing symbolized by (-) using the recursion relationship as shown in Eq. (1) to (4).

$$h_3^{(-)} = \left|\ \frac{\varphi_0}{K}\ \right| \tag{13}$$

$$D = \left|\ \frac{2\varphi_0}{K}\ \right| = 2\varphi_0 f' \tag{14}$$

Since the viewing angle is ±2.5° which corresponds to φ_0 =2.5°, the diameter (D) of the illuminated area can be simply calculated for the focal length of 90 mm from Eq. (14).

$$D = 2\varphi_0 f' = 2\times 90\times 2.5^o \times \frac{\pi}{180^o} \approx 7.85\ \ \text{mm} \tag{15}$$

IV. OPTICAL FEASIBILITY STUDIES BY USING CODE-V AND LIGHT-TOOLS

As discussed in previous section III, the diameter (D) of the illuminated area could be calculated for the focal length of 90 mm of a condenser lens by using such a simple formula as Eq. (14), where the result was approximately 7.85 mm. In order to secure the justification for this calculated value by means of Gaussian optics, the optical layout of color analyzer is testified by CODE-V [14] which is the most recognized optical design software in the world's leading developers. The optical system is, in CODE-V, constructed with the same quantities as Gaussian optical design values such that a condenser lens has the focal length of 90 mm and the viewing angle of ±2.5°, where the sensor is located on the back focal plane of a condenser lens. All the data described here are shown in Fig. 7. The exact value of the diameter (D) obtained from CODE-V is known to 7.70 mm which is almost the same value as

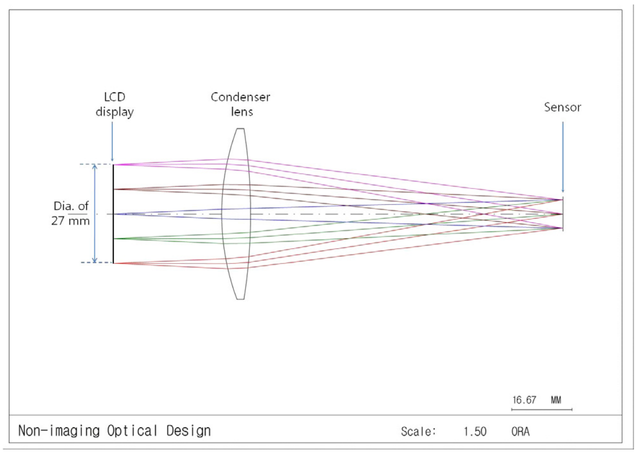

FIG. 7. The optical layout of color analyzer to be justified by CODE-V.

compared with the value of 7.85 mm by Gaussian optical calculation. Hence, it can be concluded that Gaussian optical approach is well justified in terms of a good computational accuracy for non-imaging optical system as well as giving a perspective understanding for the entire optics.

This system discussed so far can be additionally testified by Light-Tools [15] which is non-imaging optical design software well known in the world's leading developers as well as CODE-V. The system layout constructed by Light-Tools is presented in Fig. 8 and the resultant data is shown in Fig. 9 which is about the irradiance chart on the sensor when the total power emitted from the measurement area is assumed with 1 watt. Fig. 9 shows that the uniformity over about 8 mm is obtained on the sensor. And it is noticed that total rays leaving from the measurement area are taken up to 1,000,000 rays in this simulation.

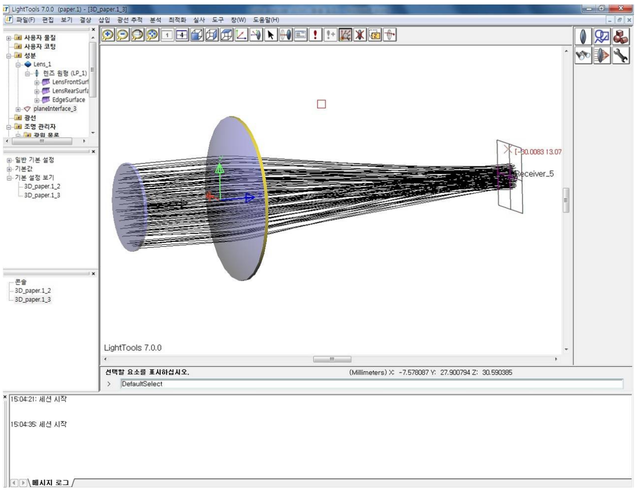

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FIG. 8. The 3-dimensional layout of color analyzer constructed by Light-Tools.

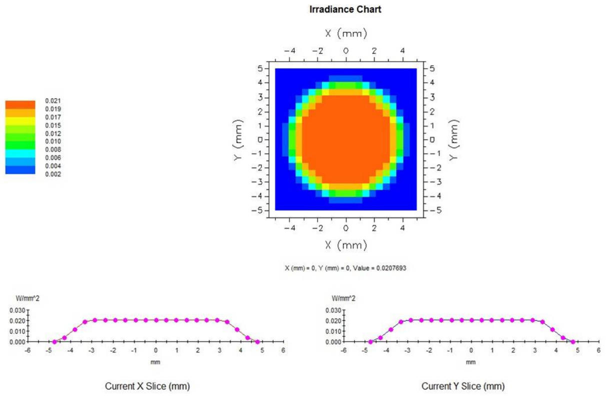

FIG. 9. The irradiance chart including x-slice and y-slice.

V. CONCLUSION

In this paper, non-imaging design technique is successfully presented based on Gaussian optics for a condenser lens used in color analyzer. Gaussian optical approach is well justified as discussed in the section IV which has described the optical feasibility by using CODE-V and Light-Tools, where the diameter of the illuminated area on the sensor is given to 7.70 mm and approximately 8 mm compared to 7.85 mm by Gaussian optics. From this justification, Gaussian optics can be recognized as a powerful tool to design non-imaging optical system as well as providing a perspective understanding for the entire optics. As a result, it can be said that this application might be a good example for a thoughtful design with Gaussian optics without regard to imaging or non-imaging optical system. And it is so appreciated that this study let us confirm the usefulness utilizing the traditional optical design approach based on Gaussian optics as well as Seidel third order aberration.

감사의 글

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