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Development of a color mixing instrument for color vision measurement

ABSTRACT

In modern color vision testing there is currently no instrument to analyze the color identification properties of human color vision. At specific tests colored or painted samples are shown to the subjects as color naming tasks [2, 3]. The main reason for this is that common color displays such as CRT or LCD screens, which would seem to be the most adequate in instrumentation of testing, have limited capabilities in displaying colors in a spectrally correct way. This is because such devices work with three primary colors and the colors they display are limited to the additively mixed spectrum of these. To test the color identification properties of human color vision in a spectrally correct way we have developed a new instrument using LEDs.

INTRODUCTION

In our Department we have been working on color vision research for more than 20 years. Our experiments and experiences show that color deficient people have reduced color identification properties, a problem that our color vision correction filters can improve.

Our intention is to test color vision for real and natural objects having broadband spectral distributions. Lacking of instrumentation for such purposes we developed the appropriate instrument capable of representing color spectra for such a test application together with the corresponding test method.

METHODS

The newly developed instrument is based on the additive color mixing of light from different spectral light sources namely LEDs with peak emission wavelengths along the visible spectrum. Our system includes sixteen LEDs using a PC controlled electric circuit to adjust their light levels. Each LED has its own current generated holder circuit which has the signal assigned from the PC and holds it until alteration. The output luminous intensity of an LED is the function of the input current. This latter can be adjusted in 256 levels. A peak luminous intensity value is equalized among all the LEDs and the current values belonging to this value are divided into the 256 levels.

The LEDs are placed into the upper hemisphere of an integrating sphere (Ulbricht-sphere) built into the test instrument (Fig.1.) The light has homogeneous illuminance on the back surface of the sphere visible for the subjects through a viewing angle limiting ocular and an observation hole. Spectral intensity measurement of the LEDs at different control levels provide the basis for the color mixing of the previously measured broadband reflection spectra using calibrated spectrophotometer. The simulation of the output spectra is done by means of mathematical algorithms with limitations by the availability of commercial LEDs.

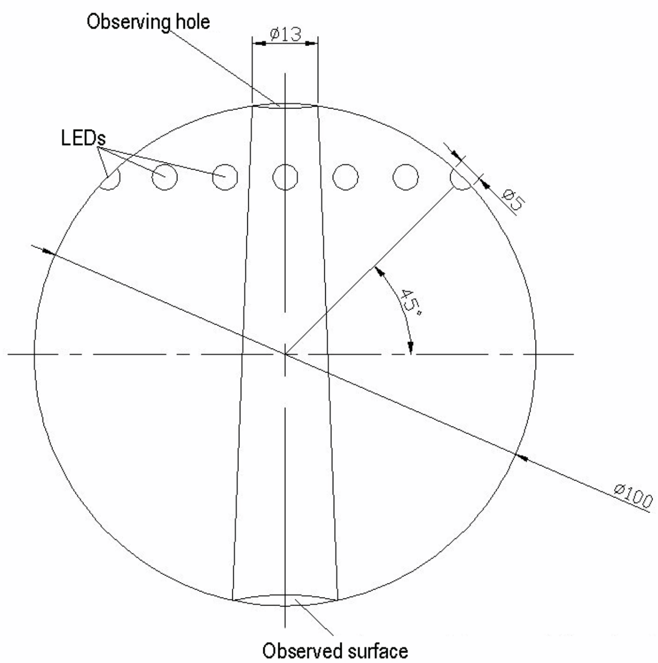

Fig.1. The core of the instrument

The test method takes the neural signals of human color vision into account [1]. Color spectra are displayed in the Organic Color System that has the unique capability to represent colors as the color normals and the different types of color deficient subjects perceive them [4].

The OCS coordinates are calculated as follows:

$$C_{RG} = \frac{L - M}{L + M + S} \quad \text{and} \quad C_{BY} = \frac{2 \cdot S - (L + M)}{L + M + S}$$

where

$$L = \int_{380}^{780} \varphi(\lambda) \cdot \ell(\lambda) d\lambda \ , \quad M = \int_{380}^{780} \varphi(\lambda) \cdot m(\lambda) d\lambda \ , \quad S = \int_{380}^{780} \varphi(\lambda) \cdot s(\lambda) d\lambda$$

where $\varphi(\lambda)$ is the spectrum of the incoming light, $l(\lambda)$, $m(\lambda)$ and $s(\lambda)$ are the spectral sensitivities of the human eye's L, M and S photoreceptors respectively.

Specific color spectra are selected for test purposes for the color deficient subjects based on modeling their color vision as known from the possible genetic alteration of photoreceptor sensitivities.

RESULTS

The different spectra displayed by the instrument are checked by means of continuous spectroradiometric measurements. The mathematical calculations and the realized spectra show good match with average errors lower than 2%. (Fig.2.)

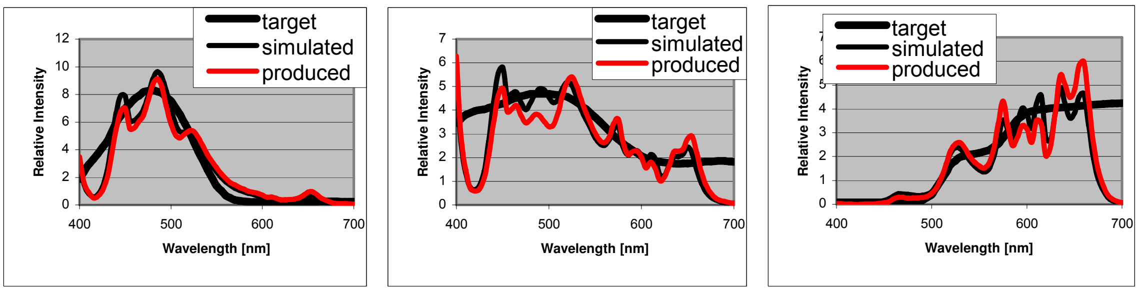

Fig.2. Some test color spectra as produced by the test instrument

After calibration and analysis on 10 subjects with normal color vision we have tested 9 color deficient subjects with the test instrument. After diagnosing the color deficiency type of each subject 50 color spectra was used for the color naming test. The results show the deviation in color naming of the different color deficients from the normal observers. We have also concluded from the measurement data that protans usually name colors worse than deutans which correspond well to the relevant literature [3].

Fig.3. shows the test colors in the OCS color space. The so called confusion colors indicated with yellow are the ones primarily and generally misidentified by the color deficients. It is well observable that these color dots tend towards the center of the color space where the desaturated white is represent and also they are elongated on the C_{BY} axis having relatively small C_{RG} values which correspond well to the red-green type color deficiency.

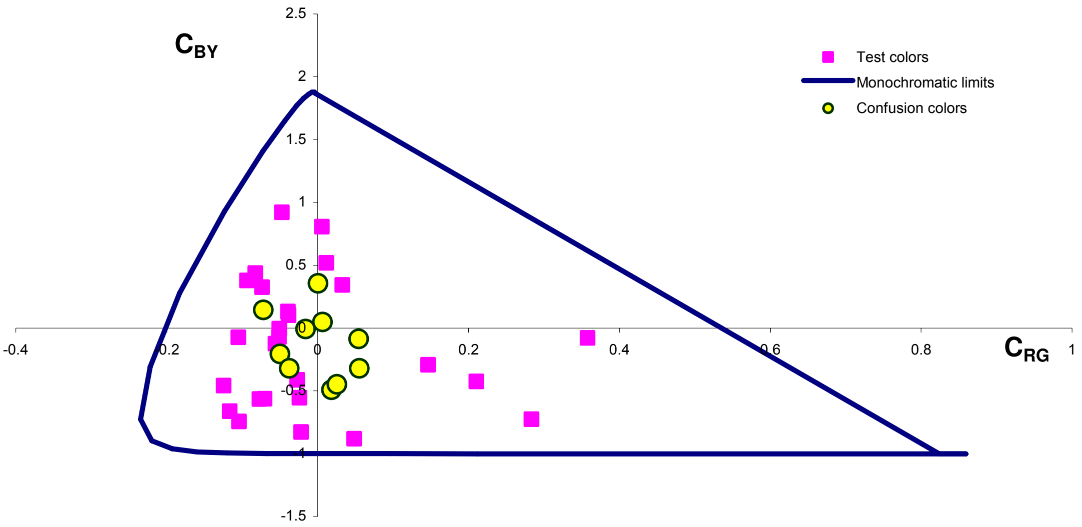

Fig.3. Confusion colors in the OCS color space

CONCLUSION

The developed test instrument has proven to be valuable in representing colors in a spectrally correct way. Using the test method we are able to determine the colors specifically misidentified by the color deficients. We have also shown that these confusion spectra primarily come from desaturated colors with dominant red-green component and relatively no significant blue-yellow contribution in the stimulus. This proves the fact that protan and deutan observers are unable to unambiguously use the red-green information for their color identification.

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