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THE SHAPE MEASUREMENT OF THE EYE SENSITIVITY CURVES

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Abstract

The main subject of the article is a project that is a part of the color deficiency correction development. To make a proper correction filter, we need to know the spectral sensitivity curves of the given color deficient eye.

In the article besides the purpose and the importance of the curve shape measurement, the basic measurement methods and tools will be made known emphasizing the color mixing methods. Presentation will be shown about a continuous curve-measuring instrument being developed by Coloryte Rt., the properties of this tool, and the possibilities of the color mixing based curve measurement development will also be demonstrated.

Keywords: color mixing, color matching, color deficiency, color vision.

1. Introduction

The scientist society had exact knowledge about the mechanism of human color vision at the beginning of the 20th century. Based upon the researches of Newton, Hering, Maxwell, Rayleigh, Helmholz, Troland W.D Wright, J. Guild and their colleagues worked out the color mixing functions in the 1920-30 years. In 1931, based on these curves the CIE standardized the normal color mixing functions, and described the sensitivity curves of the color sensitive receptors [2], [7].

We have numerous methods to describe the color sensitivity curves, but none of them are perfect. Here are the short descriptions of five methods.

The first is the color mixing which is the subject of the next part of the article.

The second attempt was getting out the light sensitive pigments directly from the retina. The third method is the eye inspection with microdensitometry. The basis of this measurement is that, if a thin light beam is reflected on the retina, we can measure the absorbed light from the reflected part. If we suppose that the absorbed light is the function of the breakdown of the pigments we can calculate the sensitivity curves. These curves are in good correlation with the curves calculated from the color mixing curves [3].

In the fourth measurement the frequency coded nerve response is measured, which is generated by different colored lights. The color stimuli were tried to be described by the analysis of these signals.

Along the visible spectrum we can measure the color discrimination ability curve of the eye. This curve is the function of the sensitivities of the three types of the receptors, so theoretically we can deduce the sensitivity curve shapes from this.

It is worth making mention of a method developed at the Technical University of Budapest. It is based on the supposition that discrete colors belong to the characteristic points of the sensitivity curves like endpoints, intersections and maximum places. If the patient's task is the searching of these precisely defined colors, we can conclude from this to the shape and place of the curves.

2. Color Mixing Methods

The color mixing methods are the same age as the color knowledge. Newton made color-mixing experiences already 300 years ago. From that time many famous scientists have taken care of the measuring methods improvement and accuracy increase. In 1856 Maxwell built a color-mixing instrument. After this in the 1920s W. D. Wright and J. Guild, independently from each other, made other color mixers based on the same principle.

Nowadays, the most accepted measurement layout is W. D. Stiles's instrument. It takes up a full small room [3]. There were some attempts to develop simpler instruments, but without demand they did not go into general use. Their spread was prevented by the fact, that for example with the Spectrotest (it is a German instrument built in 1981) the measurement of one sensitivity curve has taken three hours, and the handling of the machine was a little bit complicated [4], [5].

2.1. The Purpose of the Color Mixing

The response signals in the brain to a hue are examinable without direct intervention to the eye with color mixing. In accordance with the Young–Helmholz theory there are three types of receptors in the eye. These are the red, green, and blue sensitive cells. If we want to make correct measurement or calibration where the human eye is a part of the measured optical system, we need to know the sensitivities of these receptors. Fortunately the sensitivity curves of the color normal are very similar, so in most of the cases we can use the colorimetric standards.

The sensitivity of the color anomalous people are different from the normal one [3], and to the examination of the correction possibilities, we need to know the exact places and shapes of these three curves.

2.2. The Theory of the Color Mixing

According to the classical theory of the color mixing, if a colored light (a measuring light) is projected to a part of a divided viewing field, then with the projection of three other properly selected monochromatic lights (primaries), the two sides of the viewing field can be adjusted to the same hue.

For example see the *Fig. 1*.

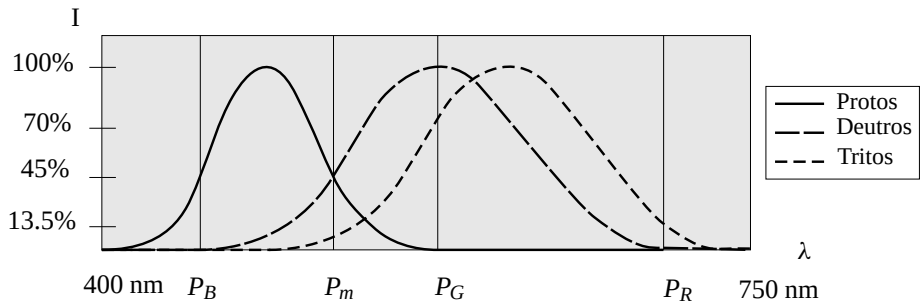

Fig. 1. Sketch of the receptors sensitivities

Here we can see directly the reactions of the receptors for different wavelengths. P_B, P_G, P_R mark the primaries, and P_m is the measuring wavelength. At the first time we can see at the one half of the viewing field the measuring wave length, and at the other side the mixed three primaries. The task is with the change of the intensities of these four lights to let the same hue in the two sides of the viewing field. One of the three primaries can be brought to the other side. As shown in the Figure in the response for the measuring light, blue and green stimuli are the same, so to the other side we have to mix blue and green primaries that cause the same response. For this, P_G has to decrease to the 45% of its maximum value. If we made it, the ratio of red and green stimuli in the mixed light is 70%, but we need only 30%, because in the measuring light there is this ratio. P_B and P_G are not changeable, because their ratio is fixed. We cannot mix P_R into these lights, because it has to decrease. So we need to mix so much red into the measuring light, so that at the side of the measuring light the Deuteros – Tritos stimulus ratio could reach 70%.

If we made it, then we have the color-matching-function point that belongs to the P_m wavelength. There is in *Fig. 2* the full color matching function. There are the values of the mixing colors at every wavelength to reach the agreement.

The negative values mean that the actual primary is mixed to the measuring light. We can see the intersections of the curves and the ordinate axis, they are at the wavelengths of the primaries. So different matching curves belong to different set of primaries, but these curves are convertible to each other.

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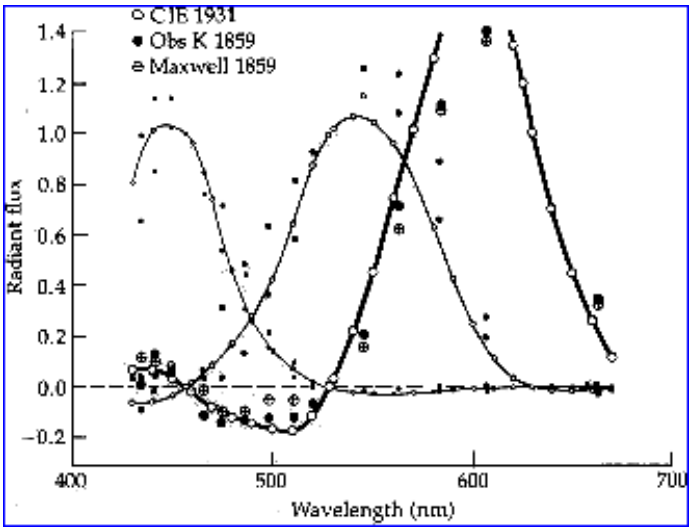

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With the aid of the color matching function we can compute the spectral sensitivity curves of the eye, but we cannot describe the size ratios between the curves. That light energy which generates a unit of reaction can be measured by the next method [3]. Suppose, that we have a standard white light. It has been projected to the one half of the viewing field, and we try to mix this white in the other side, from the three primaries. Supposed that when we see white then the three receptors signals are equal, from the last measurement the three units are computable. From these units, and the color matching function the sensitivity curves can be defined.

2.3. The Disadvantages of the Color Mixing Method

The measurement has two basic problems. The first is the inaccuracy and the second is the slowness. These two things came from the same reason. This common reason is the next.

In the light sensitive receptors the growth and fade of the pigments are dynamically adjusted for the environmental light. If the light intensity is high, the receptor sensitivity decreases; less pigment is produced, and at low light intensity the sensitivity is higher. This mechanism works in the three receptors independently. In the measurement process the patient sees different colors. His sensitivity curves are adjusting continuously for the actual hue. For example, when we go nearer and nearer to the maximum of the protos (blue) the receptor sensitivity decreases, in the case of same measuring light intensity. But we need the sensitivity curves adapted for the white light.

One of the reasons of the long measurement time is this, because between the measuring points we should stop and rest the eye, to achieve the basic adaptation

conditions. The second reason was the very problematic handling of the instruments. The third was that the measurement is really difficult, because the patients' task is the adjusting of a four free degree system, along the spectrum.

I have to note an additional difficulty that is not the problem of the measurement, but the problem of the system. When the signals produced by the receptors go into the brain, they will be the subjects of some transformations. The addition and amplification of the original red, blue and green signals have influence on the method of the sensitivity curve computation. We do not know exactly this system, but we have some theory about it.

3. The Developed Instrument

The reasons of the staring of this project were the next. The recent method that was used by Coloryte Rt. to measure the characteristic points of the sensitivity curves is the last mentioned one in the introduction. The basis of his method is something different from the accepted ones. It seemed to prove the proper working of this instrument by an accepted method. The other reason of the developing was to clear up that measurements results (of some color deficient patients), which unable to evaluate with the recent method.

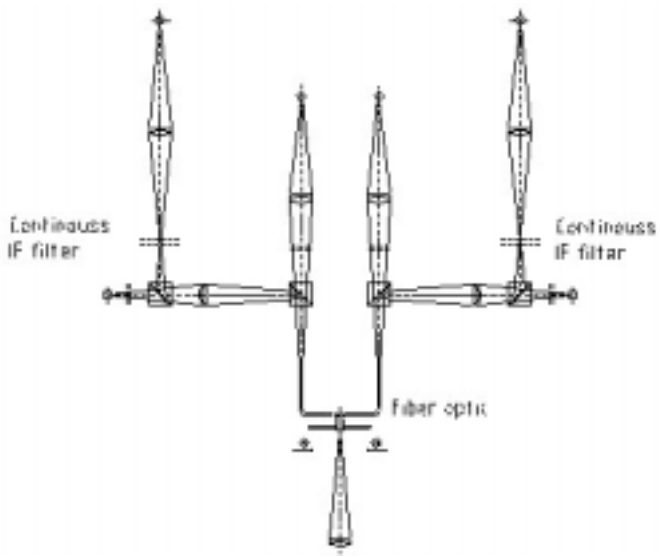

Fig. 3. The optical sketch of the color mixer

The optical sketch of the color mixer is shown in *Fig. 3.* The difference from the Stiles instrument is that to the measuring light only the red and blue primary can be mixed, but at the other side the third primary is changeable.

3.1. The Realization of the Color Mixer

By the way of introduction I would like to note that the instrument sketched here is only an experimental one, so there are possible many changes to the final version.

The measuring person who looks into the ocular sees a circle shaped viewing field divided in two halves beneath two degrees, with or without adaptation environment. The ocular can be rotated to help to deceive the identity of the two parts, and decrease the effect of the adaptation. The divided viewing field is realized with a flexible fiber optic. An independent and symmetrical optical system belongs to both of the two halves. It contains two LED-s as the red and blue primaries and a halogen lamp with continuous interference filter as the changeable light source. Two stepping motors realize the moving of the IF filters. The size of the machine is 420 mm $\times$ 320 mm so the size of a tabletop is enough for this instrument.

3.2. The Control of the Color Mixer

The instrument is fully computer controlled. Digital-analogue converters control the current of the light sources, and all of them have a feedback by photo diodes. When the instrument is turned on, the stepping motors drive IF filters going into the reset position, and the registering of the further moving and position is the task of the controlling system. The main components of the controlling system are the computer and two data acquisition cards, which receive the sensor signals, and control the motors and light sources.

3.3. Parameters of the Color Mixer

At the research phase I tried to minimize the problems mentioned in the chapter 2.3. The reasons of the full computer controlled control system are the next four things:

- The fulfillment of the data processing is going during the measurement process, so we can see the final result immediately. It is simpler to assume the goodness of the measurement, and in case of any mistake the instant correction can be applied. The administration process is executed parallel to the measurement, without loss of time.
- Some complex adjustment of the light intensity can easily be executed, and simpler to automate, like the case of mechanical, direct intensity changing. So if we want to change the intensity of several lights in parallel, according to a function, it is easy to do. If the task is to increase the strength of one light in the first half of the viewing field, but we cannot do it, or do not want to do it, then easy to automate the intensity decrement in the other half of the viewing field.

- To build in some algorithms, which ease the measurement or take it more accurate. So we easily utilize and try out the supposed properties of the sensitivity curves.
- The checking of supposed sensitivity curves can be extremely fast, so it's able to validate other measurement results. In this case the instrument projects monochromatic light, with changing wavelength, into the one half of the viewing field and in the other side it mixed from three primaries. If the supposed curves are good, then the patient will see the same hue both of the fields, while the first monochromatic light goes along the visible spectrum.

This color mixer is usable for numerous types of color measurement. The $V(\lambda)$ curve is measurable with it. This method fulfilling the requirements of the color-matching measurement described in chapter 2.2. The color-matching measurement named Newton method can be taken, where the matching light is white and the task is to produce the same hue on the other side with the mixing of two primaries and a changeable measuring light. The advantage of this method is the adaptation achieved with constant white light. The disadvantage is, that there are some places in the spectrum, where the white is not mixable with the measuring light.

3.4. The Method of the Simple Color Mixing Measurement

The instruments differ from their ancestors, because the number of adjusting variables cannot exceed the number of activated receptors at the actual measuring wavelength. This simplification is the result of the primary with changeable wavelength. We can select this primary according to the better performance, so the results become more accurate, and the measurement is faster. Here is an example for the measuring method:

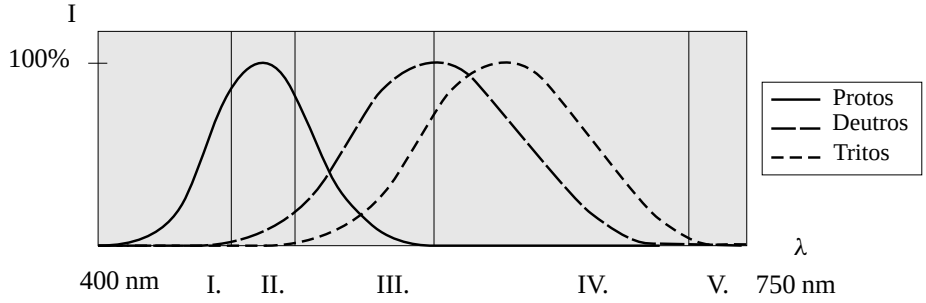

Fig. 4. The sketch of the receptor sensitivities

As I wrote in the chapter 2.2 the task is to harmonize the two parts of the viewing field. I have divided the spectrum into five parts, according to the active receptor number. If the measuring light is in the domain V in *Fig. 4*, then only one

receptor is activated. For the shape measuring we need to have a primary from this domain, and after adjustment of the intensity with the measuring light, we have to calculate the energy ratio of these two lights. After we made it with some points of the domain, then we can compute the curve shape. If the domain IV is reached by the measuring wavelength, so the two lights cannot be synchronized, then we have to adjust the changeable primary to this part of the spectrum. Now the hue of the measuring light can be mixed from this and the red primary. In the domain III the mixing process is the same as the traditional method, so we have to adjust the mixing of three primaries to reach the identity (see chapter 2.2). In the domain I and II the mixing method is consistent with part V and IV. The changing of the third primary does not cause problem, because the matching functions calculated from different primaries are computable to each other. As it was written in chapter 2.2, for the sensitivity curve calculation we need to know that ratio of the primaries which means a white to the eye, so we have to do this measurement in addition.

Of course we can do the Newton matching as well on those domains of the spectrum, where it is possible.

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