OPTOELECTRONIC METHODS OF REFLECTED SURFACES COLOR CONTROL

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Abstract: In this paper, the results of an analysis of optical-electronic methods for controlling the color of reflected surfaces, revealing their merits and demerits are carried out. Theoretical information on the basic and most widespread methods of color estimation is given, the basic concepts of the theory of color, features of human vision and quantitative and qualitative indicators of color theory are briefly described. The operation of color-measuring devices would be impossible without the existence of a stable system for displaying measured data, taking into account the further application of the results. An analysis of methods and devices for color control is also presented. Such devices include colorimeters and spectrophotometers, schematic illustrations are given and operating principles are described.

Keywords: optical electronics, color, colorimetry, dispersion, modeling, research.

In the process of biological development, the eye has turned into a subtle instrument that allows a person to notice small differences in the composition of the radiations falling into it. The study of color vision of humans has also allowed us to establish that a normal eye responds quite equally to many pairs of radiations that have nothing in common with composition, for example: the eye can not sometimes distinguish between two radiations, one of which has in its composition all wavelengths of the visible spectrum, and the other is a mixture of two or three monochromatic radiations. The visual apparatus allows a person to see under the most diverse conditions of external illumination. From a clear sunny day to a dark moonless night - these are the limits in which the eye allows you to navigate in the surrounding environment

Colorimetry deals with color relationships with a large amount of light, characteristic of daytime vision, when the rod apparatus is blinded and does not affect the light perception. In these conditions, the normal eye is able to distinguish a multitude of steps in its sensations associated with all possible relationships in the spectral composition of the radiation that enters it. The main method used to establish the dependence between the composition of the radiation and its color is the method of mixing (or summing up) the radiation, which is often called the "optical color addition method".

1. Laws of color mixing.

In order to specify the spectral composition of the radiation, it is necessary to indicate its intensity for each wavelength within the visible spectrum. And this means that it is necessary to have an idea of the composition of the radiation by adding them.

The totality of the effects produced by the eye with two radiations can be expressed by the mathematical equality sign. The whole essence of the above-described color equalities can be stated in equation

$$f'F = r R + g'G. \qquad (1)$$

Here R and G denote the colours (we will call them "single colours") of some selected radiations, ar 'and g' are the factors that indicate in what quantities the emissions corresponding to the colours R and G are mixed. The same value has a factor that we enter before the letter F, which represents some conventional single colour, whose chromaticity coincides with the colour of the composition.

The quantitative coefficients r ', g', f ', which indicate the number of units of each of the colors R, G, F, will be called the "modules" of colors r' R, g'G, f'F [1].

Every three colors are in linear dependence. And this means that any color can be obtained by mixing R and G colors or by mixing two other arbitrary colors of different colors. In this case, the number of independent variables defining the color would be two and the variety of all the colors perceived by the eye would have to be considered two-dimensional. As independent variables, or color coordinates, we could use, for example, the modules r 'and g'. The color perception of some, though insignificant, number of people has precisely these properties.

However, we are well aware that for a normal observer there are such sets of three colors from which neither can be obtained by mixing the other two. Among them belong, for example, a set of red, green and blue colors. There are innumerable other combinations of three independent colors, and therefore it is not enough to determine the color of the two variables.

The first law of mixing asserts that any four colors are in a linear relationship, although there are an unlimited number of linearly independent sets of three colors.

In general, the color is determined by three independent variables, an arbitrary color can be represented in the form of equation

$$f'F = r'R + g'G + b'B \tag{2}$$

If the single colors R, G and B are assumed to be constant (in this case they are called "basic colors"), then the independent variables are the modules r', g' and b' of the three additive components r' R, g' G and b' B For independent variables we can also take the sum of the modules of the components

$$m = r' + g' + b' \tag{3}$$

and their relations in the form

$$r = \frac{r'}{m}; g = \frac{g'}{m}; b = \frac{b'}{m}, \tag{4}$$

$$r + g + b = 1$$

The quantities *r, g, b* were called "tricolour coefficients". It is easy to see that the three-color coefficients remain unchanged with simultaneous and proportional increase or decrease of all three colour components and change with a change in their ratio in the mixture.

In other words, the three-color coefficients do not depend on the amount (brightness) of the colour, but determine its quality (chromaticity). Hence it is clear that the chromaticity is uniquely determined by two of the three coefficients r, g, b, the sum of which is always equal to one [2].

Simultaneous and proportional change of all three components entails the same change in the sum of modules, which will be proportional to the amount (brightness) of the color.

The second law of mixing asserts that a continuous change in radiation also corresponds to a continuous change in color. This law eliminates the possibility of the existence of a particular color that does not immediately adhere to all the others, since any radiation can be transformed into any other by continuous changes.

Thus, we come to the vector notion of color, from the point of view of which qualitatively different color components R, G, B acquire the meaning of component vectors having a common origin, but different directions in space, and developing according to the parallelepiped rule.

A vector image of color gives a visual representation of each mixture, which corresponds to: a diagonal parallelogram, constructed on vectors of mixed colors, if there are two; the diagonal of the parallelepiped, if there are three colors, and closing the spatial polygon, if the number of colors to be added is larger.

The linear dependence or independence of three colors is determined by the possibility or inability to draw one common plane through three vectors. In the first case, one of the three vectors can always be decomposed into composing along two others, thus constructing a parallelogram. In the second case, out of three vectors that do not lie in the same plane, no closed figure can be constructed.

The fact that every fourth color turns out to be bound by a linear equation with three colors R, G, B shows that any color can be represented by a diagonal of a parallelepiped constructed on the color vectors r 'R, g' G and b 'B. Hence it can be seen that color is a three-dimensional vector.

Taking into account that the addition of two colors under no circumstances leads to a black color, we can conclude that there are no color vectors of diametrically opposite direction. According to the second law of mixing, there can not, as we have seen, exist a separate color vector that does not belong to a common set of color vectors. It follows that all the color vectors will be located within a solid angle less than 2π.

The space surrounding the common beginning of all color vectors, each point of which is associated with the color represented by the corresponding vector, is called the "color space".

Imagine three arbitrary vectors 0R, 0G and 0B, having a common origin at the point 0 and not lying in the same plane. Let us agree that these three linearly independent colors R, G, B agree. With this, we must associate each color of Φ with a certain point of the color space and, conversely, assign to each point of the color space a certain specific color. According to the first law of mixing, any color Φ can be obtained by mixing colors R, G, B taken in certain certain proportions, which can be written in the form of equation

$$\Phi = r'R + g'G + b'B. \tag{5}$$

To measure color, optical instruments such as colorimeters and spectrophotometers are used. The effect of the colorimeter is based on the property of the colored solutions to absorb the light passing through them, the stronger the higher the concentration of the coloring substance in them. Unlike a spectrophotometer, measurements are conducted in a beam of non-monochromatic rather than polychromatic narrow spectral light formed by a light filter. The use of different light filters with narrow spectral ranges of transmitted light makes it possible to determine separately the concentrations of different components of the same solution. Unlike spectrophotometers, photocolorimeters are simple, inexpensive and at the same time provide accuracy sufficient for many applications.

2. Colourmeters

Colorimetry is the science of methods, measurement and quantitative expression of color, and the totality of such methods and means. Colorimeters - the devices that implement these methods are divided into visual and objective (photoelectric) - photocolorimeters (only objective methods will be considered in this work). In visual colorimeters, the light passing through the measured solution illuminates one part of the field of view, while the other part receives light that has passed through a solution of the same substance whose concentration is known. By changing the thickness of a layer of one of the compared solutions or the intensity of the light flux, the observer achieves that the color tones of the two parts of the field of view are indistinguishable by eye, after which the concentration of the test solution can be determined from the known relationships between them.

For the quantitative determination of color, all physical phenomena associated with the measurement of the response of a receiver to visible radiation can be used. Such a reaction is often the chemical action of light (photography), thermoelectric and photoelectric current.

At present, almost all objective colorimeters are photoelectric devices. The use of optocouplers for objective measurement of color (as well as light) is associated with many practical amenities. In comparison with photographic methods, photocells have the advantage of immediately determining the reaction (photocurrent), while the photographic action can be measured only after the appearance of the photosensitive material. The process of manifestation must always be the same, the photosensitive material is very homogeneous, which is not always easy to provide. Compared to the thermoelectric receiver, the photocell is convenient in that it does not react to extraneous sources of thermal study (for example, the radiation of the experimenter itself), from the action which the sensitive thermo element must be carefully guarded. In addition, optoelectronic converters are practically non-inertial and can work under conditions of rapid change of illumination.

Photoelectric color determinations are based on the fact that the electric current generated in the external circuit of the optoelectronic converter is proportional to the selectively perceived power of radiation incident on its surface. In this respect, the photocell acts like the human eye: both react additively to the incident radiant power, which makes it possible to calculate the effects of complex radiation by summing up the actions of monochromatic radiations.

It is known that the coordinates of the radiation color having the spectral composition I (λ) can be calculated by means of three integrals

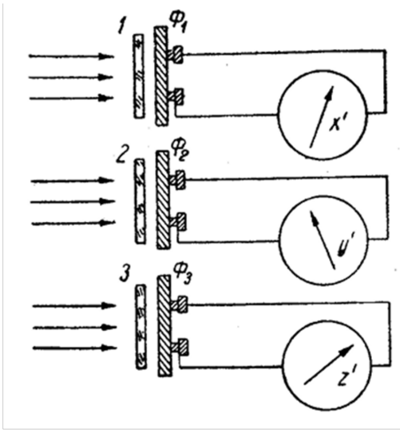

Figure 1 - Schematic diagram of the objective colorimeter

Three optoelectronic converters (Φ1, Φ2 and Φ3), before which the light filters 1,2,3 are placed, send a current to three electrical measuring devices.

When this simple scheme is implemented, where the photocurrents are directly proportional to the coordinates x', y', z' of the measured color, the selection of light filters is the most difficult part.

Proceeding from the curves of the intrinsic sensitivity of optoelectronic converters, it is necessary to go over to the previously established mixing curves x(λ), y(λ), z(λ), of which the former has not one but two maxima.

Descriptions of colorimeters of this type always contain some simplifications that entail errors in the results, and in many cases the size of the possible error can not be estimated. The usual practice is that the coordinate is measured in two steps. One time is measured that part of it that is connected with the short-wave maximum of the curve x(λ), and the other time - the part associated with the long-wave maximum. To do this, measure two photocurrent - one through the "shortwave" filter and the other through the "long wave" filter - and add both photocurrent. This path does not contain an error, but only the complication of measurement and the need to select not three filters, but four. To simplify the measurement method and to reduce the number of light filters, it is often assumed that the short-wave part of the curve x(λ) coincides in shape with the curve z(λ).

3. Portable electronic colorimeter.

The authors of this work developed a portable electronic colorimeter in which three light filters, three photodiodes and a normalized amplifier and a microcontroller with a built-in ADC, as well as reference light emitting diodes, are used to improve the speed of the reliability of the measurement process. The luminous flux, passing through the red, green and blue light filters, falls on the photodiodes, which are connected to the inputs of the normalized amplifiers, and those in turn are connected to the inputs of the microcontroller.

The method of color measurement developed by the authors consists in determining the intensity of the three components of the input light flux R, G, and B, converting this data into a digital signal for the subsequent conversion of the signal to the x and y color coordinates for the SIEH color diagram, which will unambiguously characterize the color object, the expansion of functionality through the addition of the device management interface, information display facilities, the ability to store on memory cards and the possibility of using the device in an autonomous press.

However, there was a need to improve the metrological parameters and speed of the electronic colorimeter that implements this method.

This problem is solved as follows. Digital color measuring device, contains three light filters, three photosensitive elements, a normalizing amplifier, a microcontroller. The luminous flux, passing through the light filters, falls on the photosensitive elements, which are connected to the inputs of the normalized amplifiers. Photodiodes are used as photosensitive elements. In addition, two normalizing amplifiers, whose inputs are connected to photodiodes, and outputs with analog inputs of the microcontroller, are additionally introduced. LED reference lights, connected to the outputs of the microcontroller, control buttons connected to the inputs of the microcontroller, a liquid crystal display, connected to the outputs of the microcontroller and a memory card that is connected to the outputs of the microcontroller. [3]

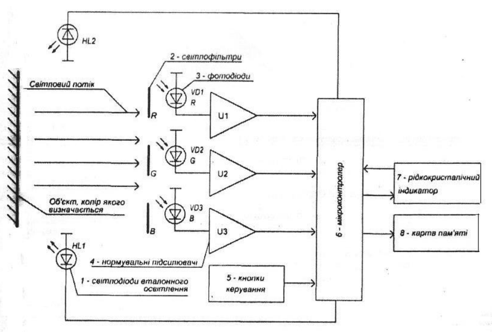

Figure 2. Structural diagram of the electronic calorimeter

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