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Rayleigh Equation Anomaloscope from Commercially Available LEDs

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Most precise classification of CVD (color vision deficits) can be provided by using anomaloscope. Today anomaloscopes are available, which can evaluate red-green (Rayleigh) and blue-green (Moreland) color defects. Our aim is to create and calibrate commercially available LEDs based anomaloscope for diagnosis of red-green color vision defects. Other field of use of anomaloscope is a seasonal and overall variation of normal color vision in Latvian population.

Keywords: anomaloscope, color vision deficits, Rayleigh match, LEDs, PWM.

1. INTRODUCTION

About 8 % men and 1 % women of population have color vision defects. Today we have tests like Rabkin's polychromatic plates, Ishihara plates [1], Farnsworth-Munsell D-15 and D-100 etc., to diagnose color vision defects. There is evidence that lighting conditions and practitioner competence have great influence on test results. In early 1907 – Nagel offered a way to diagnose red - green color vision defects, offering a device called anomaloscope. Using this equipment in practice it is possible to distinguish protanopia from deuteranopia also protanomaly from deuteranomaly with best available accuracy. [2]

Human retina contains three color sensitive photoreceptors – short, middle and long wavelength sensitive cones. Absorption spectra of all three color sensitive cells overlap which is reason why we have great sense of color otherwise we could perceive only red, green and blue color with different saturation.[3] Visual perception is an integrative process because our photoreceptors store information for 10 milliseconds and after through specific channels pass to brain to further analysis[4]. Cone signals are divided in three channels – two chromatic (S – (L + M) and L – M) and one luminance L + M where S is response from short wavelength, M middle wavelength and L long wavelength sensitive cones [5]. Rayleigh equation is a match of three colors – yellow (589 nm) and mixture of red (670 nm) and green (545 nm). It can be use to evaluate red-green dimension of color vision. The original color primaries were slightly different from what we use today, peak of green was at 535 nm and mixture of 535 nm and 670 nm can be match with 589 nm, but it appears desaturated because of blue cone stimulation. To avoid blue cone stimulation green primary should be at least 540 nm [6, 7] also greatest possible separation between red and green primaries is desirable [8] to obtain maximal differentiation of various types of congenital color defects. Also if test field size is larger than 2 degrees and even more then congenital color defective patients may not be classified correctly [9]. Studies show that light sources spectrum properties have influence on matching range, it is proven that light sources with wide spectrum extend matching ranges, more over matching ranges may overlap each other what makes impossible to distinguish whether individual have color vision deficiency or not.

2. METHODS

We used three-channel Maxwellian view system employing three light – emitting diodes (red, green and yellow) (Fig. 1). Light from red and green LEDs was combined by dichroic beam splitter, collimated and focused on a 2 mm diaphragm what defined field of view of 2 degrees visual angle. All lenses in optical system are covered with antireflective layer to avoid unwanted glare from optical surfaces and reduce brightness loses.

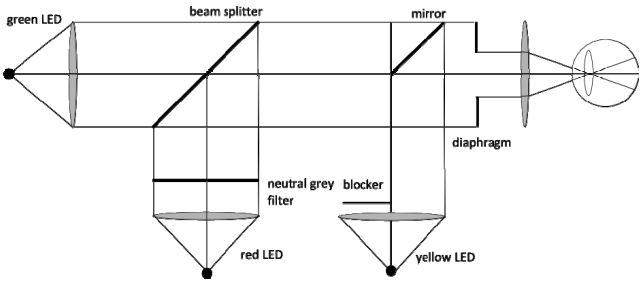

Fig. 1. Optical system consists of three plus lenses with focal length 24 mm and triplet with focal length 54 mm which serves as eyepiece, dichroic beam splitter and mirror. Mirror is used for adding yellow test field. In this system mirror is placed in 45 degree angle to reflect light from yellow LED also it serves as blocker. It is possible to move lenses forward and backward, up and down, rotate around vertical axis if it is necessary

As light sources we used light emitting diodes because they can provide necessary brightness, narrow or almost narrow spectrum with significant maximum and low power consumption properties (Fig. 2). LED anomaloscopes already have been provided by Woods [10], showing that this modification of device is good substitute for original Nagel nomaloscope.

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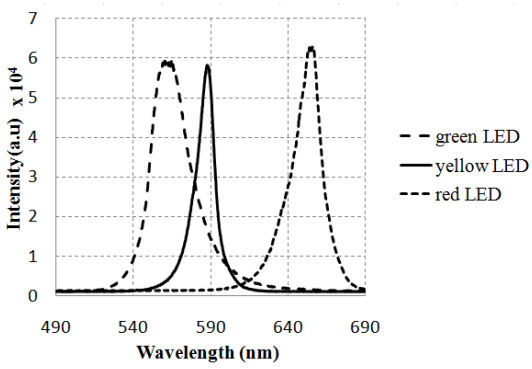

Fig. 2. Light sources spectrum properties. Green LED – 557.9 nm, width 28.1 nm, yellow LED – 587.7 nm, width 12.3 nm, red LED – 656.9 nm, width 20.4 nm

We tested two types of LEDs but no one of light sources provided necessary brightness or spectrum properties. One type of light sources produced (12 – 28.1) nm wide spectrum which is enough except green LEDs, because their spectrum should be about 10 nm wide. We also use neutral grey filter for red LED, because it was much brighter than green LED and as result all matches were too red and no one of them were yellow. With necessary modifications in device construction, it became possible to make correct matches. Calculations showed retinal luminance of 2.52 – 3.87 logTd, but it is not enough for the photopic requirements. To solve the problem of brightness – we may use power LEDs which can provide necessary retinal luminance. Only imperfection of these light sources is wider spectral half width. However, this can be narrowed by interference filters, which would increase the expenses of device. Other way how to solve brightness problem is to manufacture LED cluster from LEDs we used. This type of lightning source may provide necessary brightness and spectrum properties.

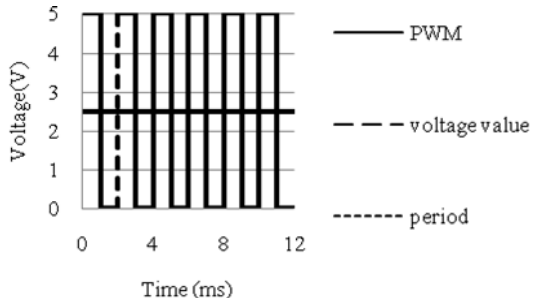

Fig. 3. PWM graphic example of 50 % duty cycle

Next task was to figure how to control the brightness of red-green primaries. The drawback of the linear potentiometer control is a lack of accuracy and dynamic depth. Direct control of LEDs by digital analogue converter via PC serial port is an easy way. However, anomaloscope needs balanced control of primaries brightness, which could result in sophisticated schematics. To solve both problems we decided to use microcontroller which allows to control up to 6 LEDs at same time with different PMW (pulse – width modulation) frequencies (Fig. 3). Using pulse with modulation technique (PWM) is possible to get analogue results with digital means. Microcontroller provide 8 bit resolution for each light source, it means that patient can adjust from minimum to maximum luminance in 256 steps. Data from computer to microcontroller is send with 500 Hz frequency so flicker cannot be perceived. Advantage of using this method is that it avoids LED heating which can lead to spectrum shifting towards to left and other semiconductors related problems. We use digital control to create square wave so light source is either switched on or off there is no transition state. LED luminance is depending of pulse with length (duty cycle), the longer it is switched on brighter it looks.

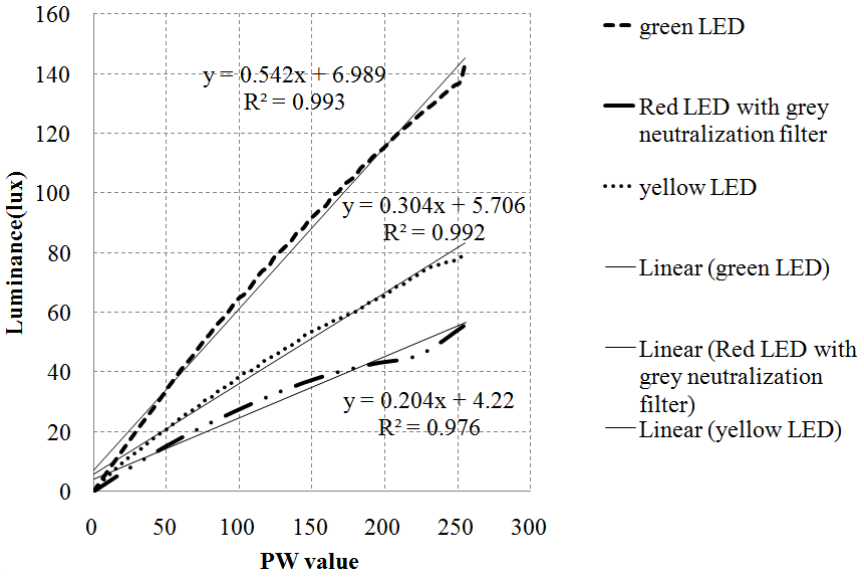

Fig. 4. All three LEDs luminance is linearly dependent on pulse width value. Using linear regression models we can calculate luminance knowing pulse width value. If it is necessary we can change brightness proportion between LEDs

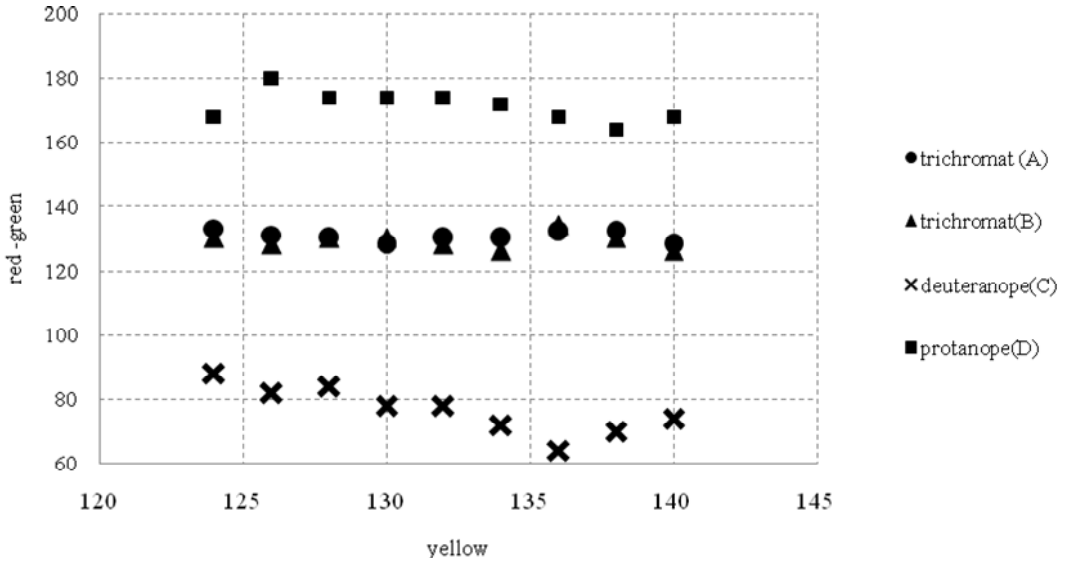

Fig. 5. Matching points for 2 patients without color vision deficits (A and B) and with CVD (C and D). As we expected, patients A and B matching points fit their matching range. Patients C and D can match red-green primaries with yellow over much wider range that show their severity of CVD

Calibration

Light emitting diodes were calibrated using lux meter placed in device optical system. For red, green and yellow LED we took 65 measurements in each measurement increasing pulse with value for 4 units. Same procedure was repeated with red LED and neural grey filter in front of it. Neural grey filter was used to make red LED less brighter then green LED to make approximate lightning proportion between them 1 : 2 [6]. All results were plotted in graph (Fig. 4). For all three curves were found linear regression models using least square method. For all light sources we got strong connection between actual curves and linear regression models – yellow = 0.9924, red (with neutralization filter) = 0.9769, green = 0.9939. Also red – green LED proportion is 1 : 2.65 which is acceptable.

Procedures

The examination procedure is in two steps. First we let patient to make a few exact matches by adjusting red-green ratio and yellow test field luminance. In next step examiner sets red-green ratio and asks the subject to make a match by adjusting yellow test field luminance, if it is possible. To operate anomaloscope procedure requires knowledge, because after few measurements examiner must be able to tell whether patient have color vision deficiency or not, if he has it that what type of disorder. Individuals with normal color vision make almost identical matches, but protanomalous patients in red-green mixture add more red, deuteranomalous patients add more green. Both matching ranges are more extended than normal. In their cases extension of matching ranges show severity of color discrimination [1]. Protanopes may be diagnosed by matching pure red with yellow in this case we expect that subject will set low yellow test field luminance. Deuteranope will set almost same yellow luminance for pure red and green. [2]

Observers

20 subjects participated in study, 2 of them carriers of color vision deficits. 19 participants were of 21 – 23 years of age (average age 21.9 ±0.11 year) one participant was 45 years old.

3. RESULTS AND DISCUSSION

This equipment allows telling whether patient has or hasn't color vision deficiency. Normal color vision patients make matches almost equally. Data from these patients can establish normal matching range [11]. We have already tested persons with color vision deficiencies and classified them correctly. Protanomalous patient fail to mach red-green with yellow by adding more red as necessary. In next step we asked to match pure red with yellow. Patient answered that it is impossible to make a mach so we classified him as protanomalous. Other patient fail to match red – green with yellow by adding more green, but he miss match pure green and pure red with yellow, because matches were to different so we classify him as deuteranomalous. Both cases our results confirmed by other tests. At the moment we cannot evaluate severity of defects because it is necessary to establish matching ranges for defective color vision.

First experiment participated 4 subjects 2 of them color vision carriers (Fig. 5). Before anomaloscope test all 4 subjects were tested on Isihara test and as expected 2 subjects (C and D) fail this test. In anomaloscope test 8 measurements were made for each patient. Examiner set yellow test field luminance from 124 to 140 increasing luminance for 2 scale units in each test. Patient was asked to adjust red – green proportion till both sides of test field looks exactly same or very similar. Subjects (A and B) without color vision deficits results vary 2 to 4 units on red – green scale between them. One of color deficient patient (D) choose add 42 to 70 scale units more red luminance

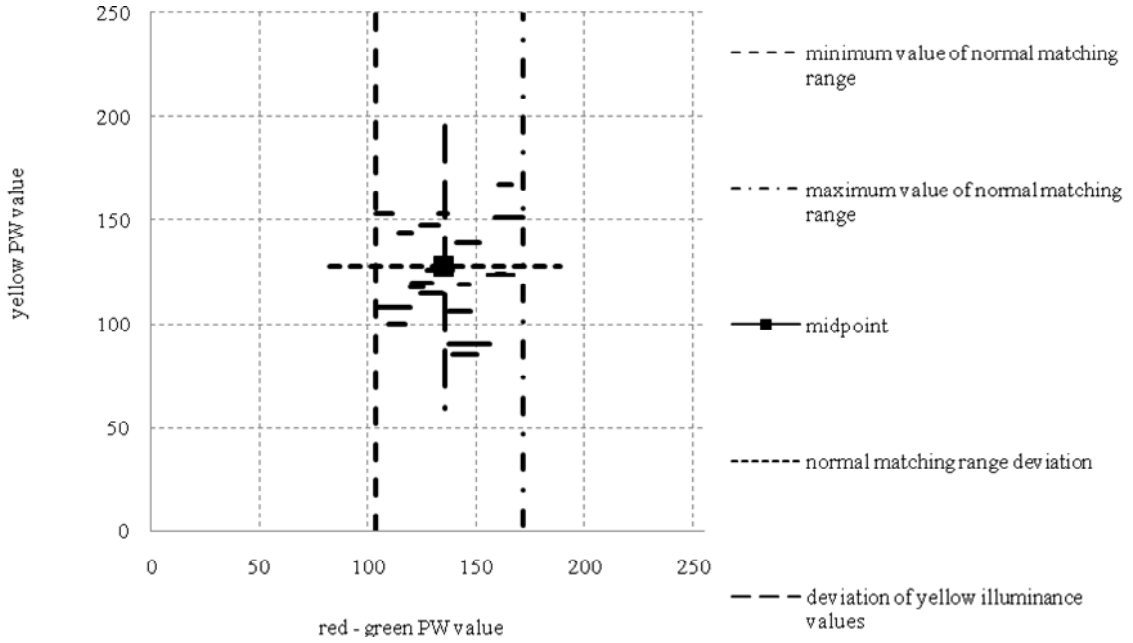

Fig. 6. Matching ranges were 9 ±1 units with deviation 4 units. Industrially produced anomalocopes red green scale are from 0 to 73 and matching range from 42 to 44 units on red – green scale. If we compare scales proportionally that 89 % of our patients matching ranges fit in normal matching range

than subjects A and B what point to protan color vision deficit. Subject C choose add 32 to 52 scale units more green than subjects A and B what points to decreased sensitivity on middle wavelengths.

For second experiment we picked 18 students without color vision deficits and determined their matching range (Fig. 6). Reason for this experiment is to find out our device normal matching range. For each experiment participants were determined matching range, midpoint of matching range. From gathered data we calculate device mean value on red- green scale 135 ±4 , dispersion 18 units and determined normal matching range from 103 to 171 scale units on red-green scale which is little bit disappointing, because less difference is desirable. Yellow test field luminance varied from 85 to 165 scale units among test subjects.

4. CONCLUSIONS

We have built device to diagnose color vision defects and already have classified few persons. Anomaloscope data tie with other tests. However diagnosis is based on our skills and knowledge so we can classify deficits, but can't evaluate severity of defect. To make accurate measurements device needs to be calibrated. It can be done by testing large number of subjects with and without CVD. For further researches we should increase unit value on red-green and yellow scale which will narrow device normal matching range.

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