COLOR MATCHING OF LIGHT EMITTING OBJECTS IN AUTOMATISATION PROCESSES: MODERN METHODS TO GUARANTEE THE COLOR AND FUNCTION OF LEDs

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Abstract

In the present contribution, the function of modern color sensors has been discussed. The determination of the color of 15 red and 15 orange LEDs presented in the paper, has been used as a model case to demonstrate the function of such sensors. To guarantee function and correct color of LEDs in implementations of automated production processes, such information is crucial. For an example, the VE-0006 of Vulkan Electronic has been studied.

1. Introduction: Where are the problems?

In recent years, we have seen a huge increase in applications of Light Emitting Diodes (LEDs) in day to day life. They can be found in a huge number of high technology tools, effecting all branches of civilisation. To name only a small number, one may think about laptop screens or cockpits or even warning lights in our cars.

Even in very simple cases, LEDs are used. For example, a single LED often shows, whether appliances are switched *on* or *off*. Cases, where such a single LED is telling us whether your computer screen is switched on, are not severe. However, imagine your car got a warning LED, which is lighting up in the case that the oil level of your engine drops below a certain value. Is this diode out of order and the level drops below the allowed minimum, the engine of your car is going to stop running very soon. Reflecting on their use in medicine, such failures are going to cause personnel tragedies. Thus, manufacturers must guarantee that LEDs being installed in their products are working.

Slightly more difficult is the case, where the different color of LEDs are telling the observer well defined information. Often, green is used to inform appliance works alright, whereas red means warning or without function. Imagine, you would build a simple control display with a green and a red LED. For example, red might indicate that a certain machine can not be serviced because of danger to the engineer, whereas green stands for service can be carried out. An electrician might start his work since the green color LED is giving the signal of no danger. Unfortunately, in the automated production process there has been an interchange of the red and green LEDs. This might kill the electrician. Thus, manufacturers must guarantee the color of LEDs installed.

To verify, whether the automated implementation of the LED has been right, it is still very common to use the human eye for the final test. This method is often applied, since the use of spectrometers is extremely expensive and in a huge number of modern production processes spectrometers can not be applied at the right position.

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The paper is organised as follows: in section 2, the color sensor VE-0006 used is presented, discussing its function and principles of color matching. A simple application is demonstrated on the test series of 15 red and 15 orange LEDs in section 3. Finally, a conclusion and a future work has been pointed out.

2. A modern colour sensor like the human eye

Here we present a sensor, which is able to characterize the color of the light emitted by objects under investigation. Below, the function of the sensor is presented whereas in the next section the model sensor is applied to the color matching of LEDs . The color matching of the eye has been intensively discussed in the literature (for example [1,-,4]). It is common to follow the concept of *trichromatic generalization*, i.e. most color stimuli can be matched in colour completely by additive mixtures of three fixed primary stimuli whose radiant powers have been suitably adjusted. There exists also other stimuli which have to be mixed first with one of the primary stimuli before a complete colour match with a mixture of the other two primary stimuli can be obtained [1].
Similar to the standard human eye, one has designed a sensor, which is able to detect the three color ranges of red, green and blue. In the appendix, figure 1 shows the basic building block of the color detection system used below. In the case illustrated, the light falling onto the sensor element has been reflected from the object under investigation. Therefore, this object has been illuminated with a white source of light. The reflected light reaching the sensor unit is producing three signals each of them representing the intensities of the different color compounds. These photocurrents can be amplified and transformed by simple amplifying, comparable with traditional photo diodes.
The heart of the color sensor used is made of three Si-PIN photo diodes integrated on chip. They are designed as equal size segments of a round disc with diameter of 2.0mm. The design of Si-PIN photo diodes allows the detection of signal frequencies up to the MHz-range. In order to achieve a suppression of the interactions between the photo diodes the individual sections are separated from each other by additional structures. Each of these photo diodes is sensitised by chip-integrated dielectric spectral filters allowing at the first segment the red, on the second segment the green and at the third segment the blue parts of the spectrum to reach the photo diodes.
Since these dielectric spectral filters have been integrated into the chip, they are located directly before the photodiodes. Thus, the sensitive part of the sensor forms a compact optical unit. Since the filters reflect the locked color ranges, such sensor units show a much longer life than units working with spectral filters based on the absorption of light.
Often in automated processes it is not possible to bring the color detector directly into the right position to control the appliances of LEDs. The sensor discussed [5,6] has been

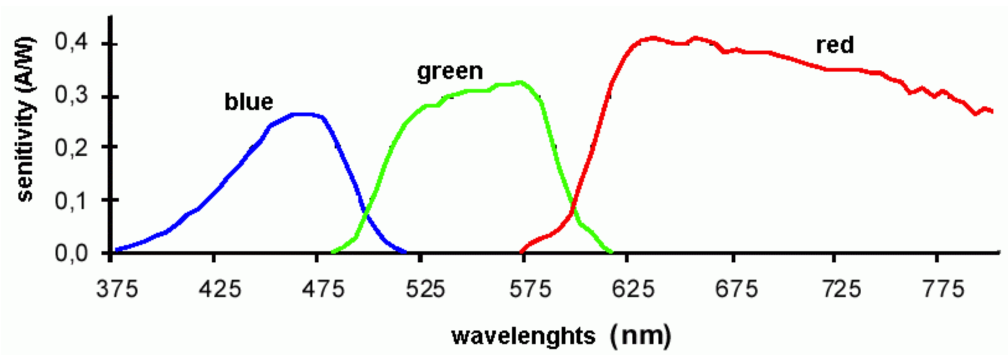

figure 1: color sensitvitys of the 3 segments of the detector VE-0006

designed with up to five fibre optic tubes, which transfer the light detected to the main sensor unit and allows a simultaneous study of 5 diodes at a time. The sensor chip itself is built into a box with a CPU and a data memory on board. It communicates to the outside via a serial port and a digital I/O port. This is shown in the appendix.
The sensor used to study color of the 15 test diodes in the following section, shows the spectral sensitivity plotted in figure 1 (see also [5]). The sensitivity of blue segment, ranges mainly from a wavelength of 375 nm to 520 nm, and the green one from 480 nm to 620 nm. For increasing wavelength, the red segment starts to produce a measurable signal around 570 nm leading to a maximum sensitivity around 650 nm before it declines slowly for higher wavelengths.
To investigate the independence of the color determination by the detector VE-0006 from the intensity of the light source we carried out two simple studies. Before all measurements, the VE-0006 facility of compensating the background radiation has been used, i.e. initialisation of the VE-0006 sensor has been carried out by measuring with the all light sources under investigation switched off.

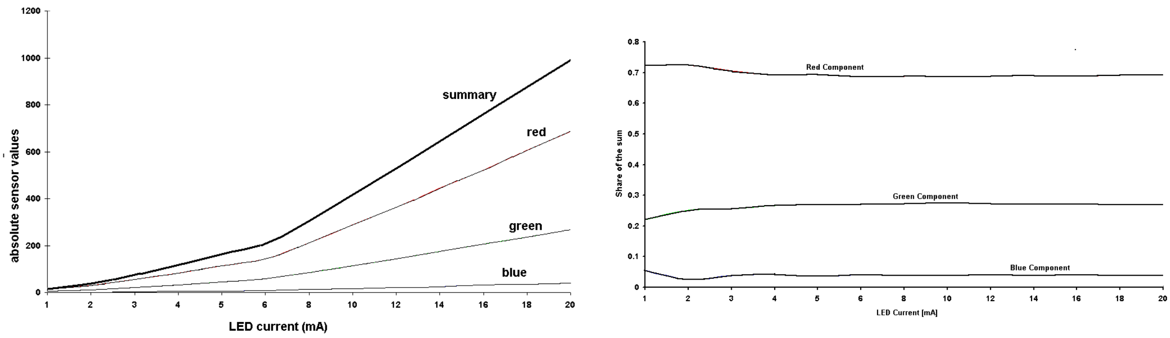

figure 2: a) intensity as function of LED current; b) color ratios as function of LED current

Firstly, we used a yellow SMD LED increasing the LED power from 1 to 20 mA. In the left part of figure 2, the magnitudes of the different signals coming from the three different segments of the sensor and their sum are shown. It is obvious, that the strongest signals are coming from the green and the red segments and that the blue is as expected rather small. All three signals show a similar increase with increasing power. In the right part of figure 2 , the same results are shown as ratios of each signal with the sum of the three signals. It is quite impressive how stable these ratios turn out to be. Whereas, the absolute intensity of the signals increase from 1 to 20 mA by a factor of 100, the ratio of the red segment remains constant at about 0.70, the green remains constant at 0.27 and the blue segment contributes about 0.03.

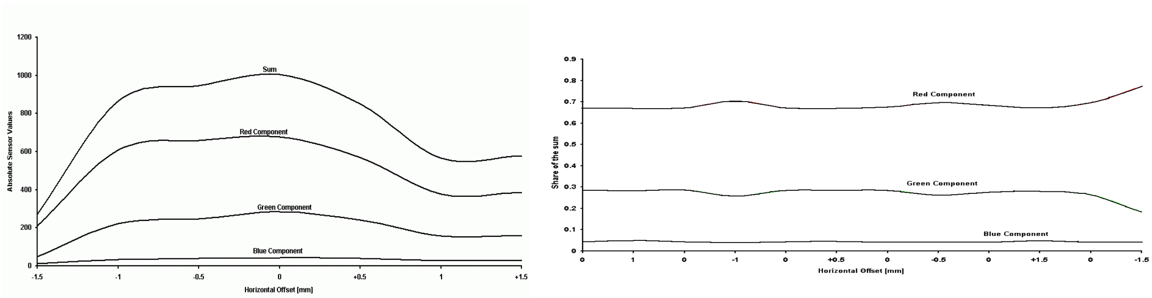

figure 3: a) intensity as function of LED shifts; b) color ratios as function of LED shifts

Secondly, we simulated the quite common case appearing in automated production: the position of the LED fixed on the produced board is not just where it should be. Often it is shifted slightly from the designed position. Therefore we investigated the case of the entrance of the fibre optic tube is not only straight above the LED tested. In our study we shifted it from –1.5 mm on one side to 1.5 mm on the other side. In the left part of figure 3, the absolute intensities of the signals are shown. The maximum is close two the middle position. To both sides, the values fall in a similar manner. As they fall deeper on the minus side, in our measurements the zero point has not been the middle point of the diode mounted. The diode has been shifted to the right. This effect could be used to determine the actual position of a LED on its board. However, here we only want to have a closer look to the color determination. As in the first case, for the yellow LED studied, the ratio of the signal from the three segments with their sum remains stable at the values discussed under the first case above (see right part of figure 3).

3. Application: Separation of 15 orange and 15 red LEDs

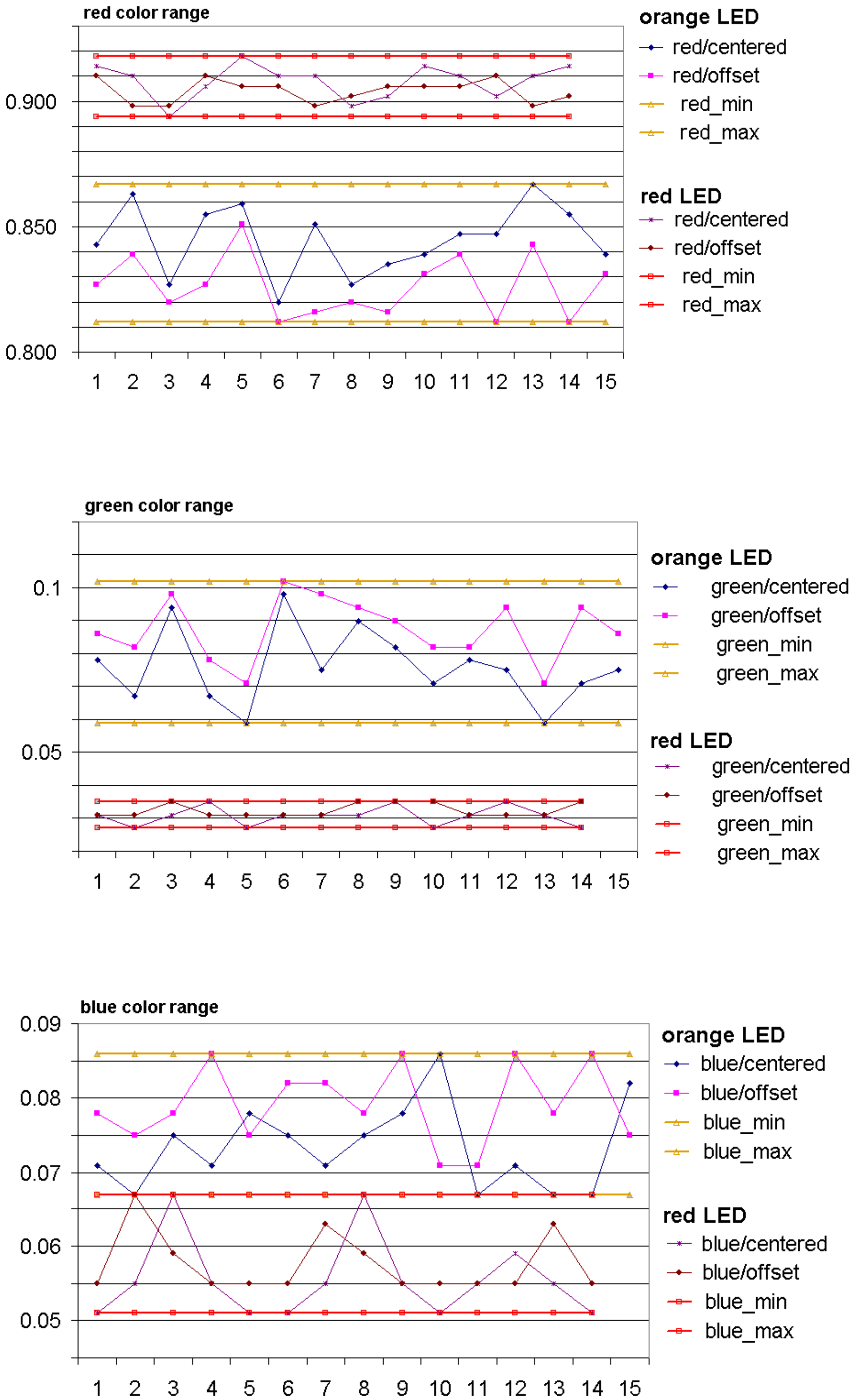

figure 4: color ratios all orange and red LED´s

Here we discussed the study of two different kinds of LEDs [7], the first are orange the second are red. The difference of the color was just recognizable by the normal human eye. However, the color matching was just so close, that there has been doubt whether color sensors like the VE-0006 could separate the two kinds of diodes. Therefore we have fitted 30 LEDs on three boards (five red and five orange ones on each). All diodes have been named with numbers running from 1-15 for the red set and also for the orange set. We assumed that the position of each LED was well defined within about 1 mm. To take care of this uncertainty we carried out two measurements, one centred and one with 1 mm offset.

The results are shown in the figure 4. In the three parts of the figure, the corresponding ratios of the red, green and blue segments are plotted. In the red color range and in the green color range of each of the three plots, it is absolutely obvious which LED emits orange and which one emits red. For the red segment, all ratios of the red LEDs are lying between 0.894 and 0.918 and all orange LEDs lead to ratios between 0.812 and 0.867. Thus, both ranges are separated and purely based on the red sector signal, the red and the orange LEDs can be separated from each other. To verify these results, the ratios of the green segment show very similar behaviour, where the lowest ratio of the orange LEDs is 0.059 and the largest of the red sector is only 0.035. Thus, here the separation has been proven too. Only the ratios of the signals of the blue component show not a strict separation of the ratios. In principle the values separate into two bands again, however there exists a small area around 0.067, where both bands overlap each other.
In the different bands formed of the two kinds of LEDs in these three colour plots, it is obvious with shifts of about 1 mm, all values still fall into these band structures, just the offset has not really a huge effect on the color. Remarkable of course is the fluctuation of the different values in each band. It shows obviously, that not all red LEDs have exactly the same red or orange color. Thus, restricting the boundaries of these bands (as possible with the VE-0006) can guarantee the color of a certain set of LEDs beyond the recognition of the human eye.
To conclude this section, these diodes which have been hard to separate with the human eye could be without doubt separated with modern color sensors of quite low costs.

4. Conclusion and outlook

Our investigation has shown that modern sensors are very effective in determining excellent information about the color of light emitting objects such as LEDs. Since such sensors work often more precisely than the human eye, they must be recommended for the usage in automated production processes.
In the future, the information gained by such sensors will be used to produce information of the color matching of objects with the human eye [8]. Color matching of objects, which do not emit any light itself, is going to be also at the centre of our future developments.

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