Design and development of a lamp of adjustable spectrum

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Abstract—Nowadays artificial light is used in many areas of human life. Dedicated lighting allows to emphasize selected features of technical and biological objects, stimulates the growth of plants or enhances the attractiveness of products or artistic works. In this paper a developed low-cost lamp with an adjustable spectrum was presented. As light sources, several LEDs of both narrow-band and wide-band spectrum were selected. A multi-channel Raspberry PI was applied for LEDs driving and ensuring the user's interface. To properly mix light from several different LEDs, a dedicated integration sphere was used, covered with paint based on barium sulfate.

Nowadays artificial lighting is commonly based on LEDs because of their growing luminous efficacy of 200 lm/W [1] or even more [2]. However, luminous efficacy is not the only parameter describing light sources. The color rendering capability and light spectrum are also important [3, 4].

Objects illuminated with appropriate lamps become more visually attractive. Thus, there are more and more dedicated systems for illuminating meat, vegetables and fruit [5]. The same requirements for lighting also occur in the cosmetics industry. Another important area for dedicated LED lighting systems is healthcare, where such systems are used for surgery light [6], endoscopic light [7], and oral cavity inspection [8]. Dedicated LED lighting systems are also used in horticulture. It is possible to stimulate the growth of plants by illuminating them with the light of a certain spectrum within a proper time [4, 9–10]. Adequate lighting plays also a key role for photographers and video operators, as professional photographers have to be ready to meet different expectations of their clients [11].

Most applications mentioned above require dedicated illumination systems. Unfortunately, these systems usually have a fixed spectrum, which means that for each application a different illuminating system (lamp) is needed. Additionally, in some cases, in order to emphasize an object's attributes, it is important to tune the light spectrum and choose the best one. A possible solution could be to provide the illuminating system with the characteristics of several different spectra or one adjustable spectrum, operated manually by the user or using advanced algorithms [12, 13]. Thus, a low-cost lamp of adjustable spectrum has been developed and described in this paper.

An adjustable spectrum lamp should be characterized by both well-mixed and diffused output light and a wide and tunable light spectral range. It is also expected that the emission spectrum of the lamp should be adjusted without significant affecting the output luminous flux.

It was decided to use a set of very efficient LEDs as a light engine for the designed lamp. Light emitting diodes are also one of the best light sources to control their luminous flux. Therefore, a multi-channel controller was used as a control device of the LED engine. An integrating sphere with an output hole for an output luminous flux is used to achieve the required spatial characteristics of light [14]. A system which allows to adjust the spectrum should be easy to operate. Therefore, a graphical user interface controlled by a touch screen was applied. The idea of the developed lamp is presented in Fig. 1. Finally, to combine all of the mentioned requirements and considerations, the whole system was equipped with the following blocks: an AC/DC converter for power supply of the whole system, DC/DC LED drivers, LED engine, integrating sphere for forming a diffusive and uniform output flux and mechanical mountings to provide mechanical stability of the system.

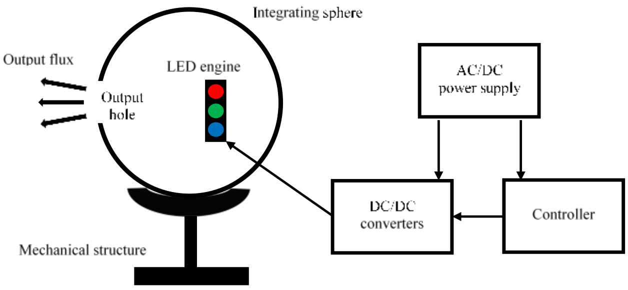

Fig. 1. Block diagram of the developed illuminating system of adjustable spectrum.

It is important to ensure high diffusive reflectance of the internal coating of the sphere. According to CIE standards [15] the paint for an integrating sphere should have the reflectance between 90% and 98%, and be

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approximately constant over the whole spectrum range. Finally, the inner surface of the sphere was covered with a specially developed paint based on barium sulphate and white latex paint [11,16]. Several compositions of barium sulphate powder and white latex paint have been tested. The best results (highest reflectance, over 90%) was achieved for the composition of 70 ml of latex paint mixed with 60 g of barium sulfate (Fig. 2).

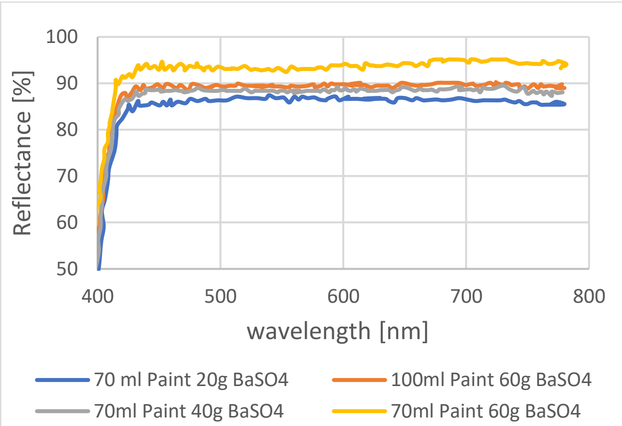

Fig. 2. Reflectance spectral characteristics of the developed painting mixture for different proportions of ingredients.

Two different procedures of painting the sphere were tested. In the first one, a certain amount of paint was poured into the hemisphere and then distributed on the whole inner surface of the hemisphere by the tilting and rotating motion, using centrifugal forces. Painting with this method was quick and a small number of layers was enough to apply a thick layer of paint. However, in this method paint cracking occurred, caused mainly by the shrinkage of a thick paint layer during the drying process (Fig. 3a).

(a) (b)

Fig. 3. Integrating sphere painting process: cracking of the thick layer of paint (a) and hemisphere during painting using a roller (b).

Solving this problem required again surface alignment and cleaning, and then refilling paint cracks, which was a very time-consuming process. Additionally, it was difficult to obtain satisfactory surface uniformity. In the second method, the integrating sphere was roller painted using, by repeatedly applying thin layers of paint (Fig. 3b). This method was very time-consuming because of required long paint drying before the next layer could be applied. According to the guidelines provided by the manufacturers of integration spheres, 11 layers have been applied, obtaining a total layer thickness of about 400 µm.

As a light source, 9 narrowband and 4 wideband LEDs were selected. Analyzing only the narrowband LEDs, it can be noticed that there are many local maxima and minima in the synthesized spectrum. To overcome this problem, wideband spectrum LEDs (white LEDs) were added, as in most expected applications the most important are different variants of white light, slightly or much more modified. However, using white LEDs (with a different color temperature CCT) is less energetically efficient than using more narrowband LEDs of different wavelengths, mainly due to the losses during the phosphor excitation-emission process. Additionally, the LED number has to be a compromise between the adjusting accuracy of any required spectrum and the ease of controlling and setting the preset spectrum.

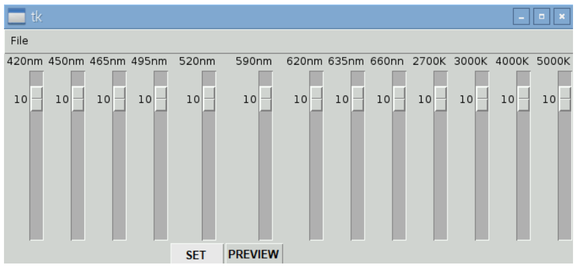

Fig. 4. The main window of the graphical user interface.

The main control unit of the device was based on a Raspberry Pi3 controller with a 7-inch touch screen. The main window of the graphical user interface (GUI) was shown in Fig. 4. There were 13 sliders responsible for controlling individual LED channels (PWM modulation). Each slider could be set in the range from 0 to 100, which directly corresponds to the relative intensity (in percent) of the individual LED channels. A change of settings was entered into the system after pressing the "set" button.

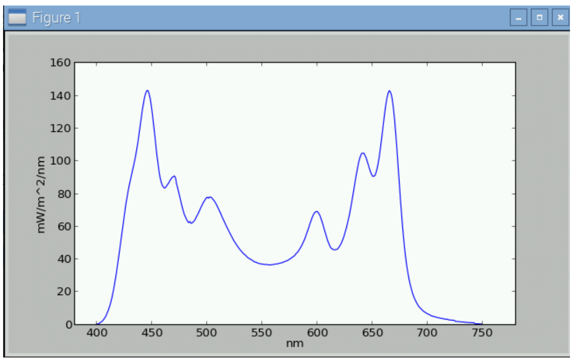

Fig. 5. Previewed spectrum chart.

The set spectrum can be previewed by the user using the "preview" button. This spectrum is an estimation based on the set values (in percent) and typical spectral characteristics of individual LEDs. The spectrum is displayed in the GUI window in the visible range, which corresponds to a wavelength range of 380–780 nm (Fig. 5).

The mechanical structure of the lamp consists of structural elements mounting the sphere (6063-T5 aluminum profiles), integrating sphere itself (two hemispheres with a diameter of 36 cm, and the output hole with a diameter of 120 mm, with a LED module inside), and the plastic housing of the controller. An external view of the mechanical structure of the device is shown in Fig. 6.

Fig. 6. External view of the mechanical structure of integrating sphere-based lamp with control panel.

The main task of a lamp with an adjustable spectrum should be its ability to generate light for many applications, with the spectrum set by the user. In order to verify the correctness of the estimation process (previewed spectra), a series of test spectra were set (previewed). In the next step the corresponding actual output spectra were measured using a GL Optic Spectis Touch 1.0 spectrometer. An exemplary spectrum was presented in Fig. 7. The blue line represents the previewed (estimated) spectrum, while the green line represents the measured spectrum.

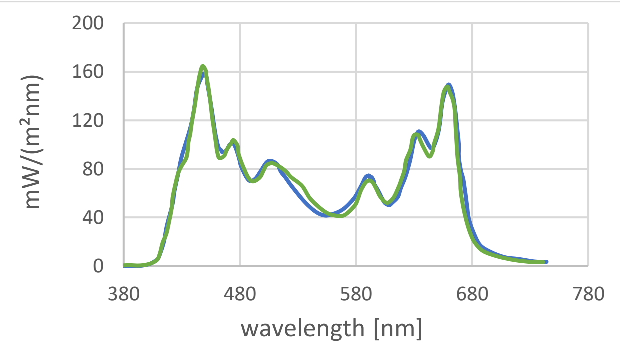

Fig. 7. Modeled (blue line) and measured (green line) characteristics of the test spectra of the developed lamp.

As it can be noticed, a satisfactory agreement between the predicted and the measured spectral characteristics of the output light was obtained [15]. Small differences that occurred in some tests were mainly caused by the adopted simplifications (linearization) in the estimation process. In summary, the developed lamp can be an interesting, low-cost alternative for a wide range of applications.

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