# Computer Controlled Set of Light-emitting Diodes for 2D Spectral Analysis

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## Abstract

*We propose a novel approach for fast acquisition of multispectral images. Key-element of the proposed approach is the computer-controlled light source. It consists of a set of the light-emitting diodes and generates any predefined basic spectrum with possibility of fast switching from one spectrum to another. The feasibility of the proposed system is experimentally demonstrated by a test of metameric samples, which were correctly distinguished. Moreover, the measured data are used for fast and accurate sample recognition without reconstruction of the original reflection spectrum.*

## Introduction

Accurate recognition of color patterns is important operation for different application including medical diagnostics, control of technological processes, authentication of art and secured papers, etc. The visual discrimination of objects is carried out by their illumination and observation of the reflected light. The accuracy of the analysis depends on color the representation. Basically the color is a result of interaction between surface, illumination source, and observer.

It has been realized that widely used three-dimensional representation like RGB or YUV allows a fast comparison of the date but provides somehow limited information about object color. This color representation is tolerable for human perceptions, but not for detailed color analysis, where all components of the color spectrum are important. Measurement of reflectance spectrum at each spatial point of an object surface certainly provides high accuracy for color classification and recognition. The main drawback of the general spectral approach is a large number (from 30 to 300) of the images components measured at different wavelengths. The method of principal components analysis allows us to find an optimal (low-dimensional) set of basic spectra with which any reflectance spectrum can be reconstructed with any required precision. By using these basic spectra high compression of multispectral images can be achieved [1]. Recently, authors described novel technique for fast measurements of two-dimensional distribution of the reflection spectra in visible diapason by using vector subspace model [2]. The key system for implementation of the proposed approach was computer controlled light source capable to generate fast switchable sequence of spectral lines.

This work is devoted to design of novel light source based on fiber coupled light emitting diodes. In contrast with previous works [2, 3], the subspace vectors are implemented by parallel and simultaneous switching on light emitting diodes (LEDs) responsible for different lines of wavelength. The system is completely controlled by a computer and it allows faster working. Significant improvement of the output power of new light-source was achieved by using LED coupled with multimode fiber.

## Technique description

It is known that a linear model composed of the band limited functions with a small number of parameters forms a realistic and a compact representation for the spectral reflectance. Any particular reflection spectrum $R(\lambda)$ can be represented by a linear combination of few basic function $S_i(\lambda)$:

$$\mathrm{R}(\lambda)=\sum_{i=1}^{m} Q_i S_i \tag{1}$$

Here the coefficient $Q_i$ are real numbers, which unambiguously represent particular reflectance spectrum within given set of samples. The number $N$ of the basis functions depends on the database size complexity of the reflectance spectra, and the required accuracy of the spectrum recognition. The coefficient $Q_i$ Eq.1 is convolution of the reflection spectrum $R(\lambda)$ with the basis function $S_i(\lambda)$:

$$Q_i=\sum_{k=1}^{M} R(\lambda_k) S_i(\lambda_k) \tag{2}$$

Where $M$ is the number of wavelength intervals defined by sampling rate. Therefore, one could directly measure $Q_i$ by using illuminant, which spectral power distribution is proportional to $S_i(\lambda)$, and integrating the reflected power over the wavelength.

Here we propose a simultaneous illumination technique to implement the vector subspace method. The object is illuminated simultaneously by different spectral lines with power of $P_i(\lambda_k)$ generated by a computer controlled light source during time t, so that

$$\mathrm{S_i(\lambda_k)=P(\lambda_k)t} \tag{3}$$

As we mentioned above, the total energy of the reflected light measured during the time period t is proportional to $Q_i$. To measure $Q_i$ for a basis function containing both positive and negative values, we first illuminate the object by the spectral power distribution corresponding to positive part of $S_i(\lambda)$, second – by the negative part, and then calculate the difference. Repeating the measuring procedure for all basis functions we obtain all the coordinates in $N$ – dimensional subspace.

### *System Description*

Figure 1 shows the principal layout of the optical part of novel light source without correct scaling and angular positions of the elements. Light source consists of an array of fiber coupled light emitting diodes generating light at different wavelengths. Recent progress in LED technology makes them very attractive as a light source in spectral measuring systems.

It is not hard to collect set of LEDs generating light at different wavelengths and covering whole visible diapason. We propose to use LED coupled with multimode fiber for increasing of the output power of the light source. Respective optics including collimators and properly designed diffractive optical element provides emission of all LEDs to be directed within the same angle. In addition, a slit is used to control the bandwidth of the output spectral lines. The electronic unit of the light source was designed to provide the injection current of LEDs and the width of the slit. By this way an operator may form color vectors, which are different sequences of spectral lines with different output power. It is worth noting that the power of one spectral line also depends on its width when other conditions are the same. By increasing the bandwidth of spectral line from 5 nm to 20 nm the optical power increases at 1,5 times. Two adjustable parameters, the power and the bandwidth of spectral lines, give possibility to find proper solution for different applications.

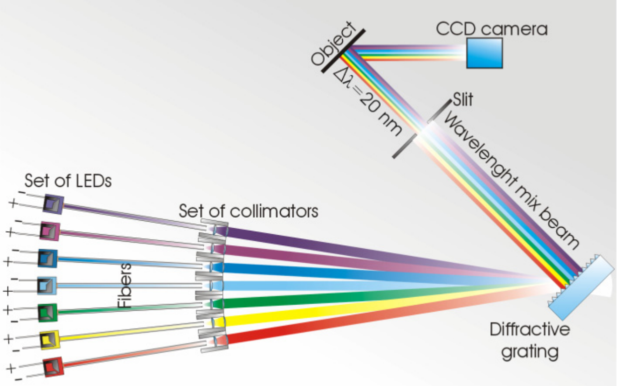

***Figure 1.** Principle layout of the light source*

The light source is synchronized with CCD camera according to the system working algorithm. The CCD camera operates in the integration mode and it acquires the spatial distribution of the reflection spectra in the compressed form. These compressed data are directly used for accurate color classification on recognition without reconstruction of the reflection spectra.

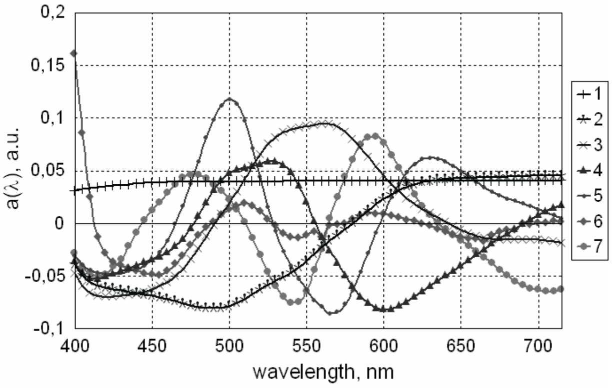

***Figure 2.** Spectral dependences of seven eigenvectors 1 - crosses, 2 - triangles, 3 - diamonds, 4 - circles, 5 - dots, 6 - squares, 7 - asterisks calculated for the set of 1257 spectral reflectance from Ref. 1.*

It is also possible to use the light source for routine spectral measurements simply scanning the emitted wavelength over the available diapason. In this case the output power may be adjusted to be the same for all wavelengths or to compensate the spectral response of the photo-receiver.

## Feasibility of Proposed Technique

Feasibility of the approach was demonstrated by checking ability of the system to distinguish samples with small hue difference. Four color samples of the metameric kit were chosen as the test object. Under daylight illumination colors of these samples are hardly distinguishable within the conventional trichromatic system.

We used seven eigenvectors calculated in Ref.1. Each sample was illuminated by the vector $S_i(\lambda)$ (see figure 2). Light reflected from the surface was collected into a photodiode. Repeating the measurements we get the components of a seven – dimensional vector $Q$, which characterizes the spectral reflectance of the sample. The dot product, Rmn of the normalized vectors $Q$ was used for estimation the difference between the samples color:

$$R_{mn} = \sum_{i=1}^{7} \frac{Q_i^m Q_i^n}{\left|\vec{Q}^m\right|\left|\vec{Q}^n\right|} \qquad (4)$$

Here symbols $m = (1..4)$ and $n = (1..4)$ identify the sample from the metameric kit.

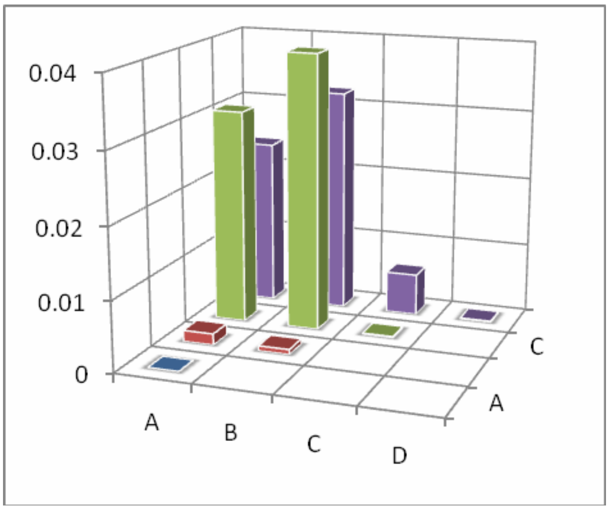

***Figure 3.** Difference of inner product of normalized 7D – vectors, which represents the reflection spectra of the metameric samples*

3D – diagram in Figure 3 shows the value of 1 - Rmn for all possible combinations of samples. Diagonal elements ($m = n$) relate to the difference in dot products of 7D – vectors measured at different areas of the same sample of the metameric kit.

It is worth noting that in comparison with Ref. 2, we used spectral lines with bandwidth of 20 nm. Our results show that comparison of the absolute maximum for diagonal elements ($\Delta Rmn$ = 0.0007) with the absolute minimum for non-diagonal elements ($\Delta Rmn$ = 0.0019) clearly indicates that even in the case when the bandwidth of each spectral line is about 20 nm, the metameric samples are surely distinguishable.

## Conclusion

In this paper we described a technique to implement the subspace vector model for fast measurements of two – dimensional distribution of the reflection spectra in visible diapason. Feasibility of new approach was successfully demonstrated in the experiment with the metameric colors, which were correctly distinguished even bandwidth of spectral lines was 20 nm.

The proposed novel LED light source may be very useful for industrial online color monitoring. The presented approach of the precise color classification and recognition can also find applications in systems for security document authentication, where the distinguishing of colors can be very important.

## Acknowledgments

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## Author Biography

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