THE COLOUR SPLITTING SYSTEM FOR TV CAMERAS - XYZ PRISM

Jan KAISER [1], Emil KOŠŤÁL [2]

[1] Dept. of Radioelectronics
Czech Technical University in Prague
Technická 2, 166 27 Praha 6
Czech Republic

[2] Czech Embassy
Ryvangs Allé 14, 2100 Copenhagen 0
Denmark

Abstract

One of the dominant aspects, which prejudices the quality of colour image reproduction, is the first operation in TV chain – scanning. Up to this day, the colour splitting system, working in RGB colorimetric system, is still entirely used. The existence of negative parts of the colour matching functions $\bar{r}(\lambda)$, $\bar{g}(\lambda)$, $\bar{b}(\lambda)$ *causes complications by optical separation of partial pictures* ***R***, ***G***, ***B*** *in classic scanning system. It leads to distortion of reproduction of colour images. However, the specific technical and scientific applications, where the colour carries the substantial part of information (cosmic development, medicine), demand high fidelity of colour reproduction. This article submits the results of the design of colour splitting system working in XYZ colorimetric system (next only XYZ prism). Shortly the way to obtain theoretical spectral reflectances of partial filters of XYZ prism is described. Further, these filters are approximated by real optical interference filters and the geometry of XYZ prism is established. Finally, the results of the colorimetric distortion test of proposed scanning system are stated.*

Keywords

TV colorimetry, scanning system, interferential filters, TV reproduction, colour gamut, colour distortion, JND

1. Introduction

The colorimetry of all contemporary TV standards (analogue as well as digital) amanates from original design of TV standard NTSC. At the time of the design of this TV standard there was cathode ray tube as the only display device. The conventional scanning system (RGB prism) is identified by reproductive lights of this display and by a comparative white light. However, today the market offers many kinds of display devices, e.g. LCD and plasma displays. The new displays have other, sometimes preferable colorimetric features, but we cannot take advantage of the better features with regard to dependencies on conventional RGB system [1]. On the other hand, the TV camera, which scans in colorimetric system of unreal lights **X**, **Y**, **Z** is not predetermined by the colorimetric features of any display device. Theoretical spectral reflectances of partial filters of XYZ prism correspond to the colour matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$, that are only positive [2]. It solves a number of problems, which are known during realization of conventional scanning system (RGB prism). The camera working in colorimetric system XYZ produces electrical analogs of trichromatic components *X*, *Y*, *Z*. Then every kind of display devices has a circuit of colorimetric transformation from the system of lights **X**, **Y**, **Z** into the system of primary (reproductive) lights in given display device. An advantage of colorimetric system XYZ is also that, that one of the scanning channel is directly the channel Y. In this case, its noise is identified only by its own scanning device. The two remaining channels (X, Z) carry an information of colour [3] and already by realization of such camera we can bargain for lower resolution of details in X and Z channels.

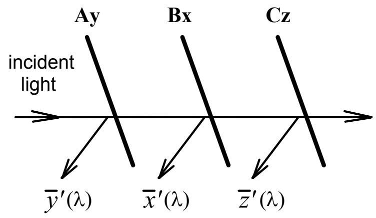

Fig. 1 The sequence of separation of partial components (images)

2. The spectral reflectances of partial filters of XYZ prism

On basis of Fig.1, system of 3 equations for spectral sensitivities of partial channels $\bar{x}'(\lambda)$, $\bar{y}'(\lambda)$, $\bar{z}'(\lambda)$ of proposed scanning system can be compiled. Spectral reflectances of partial filters $\mathbf{Ay}(\lambda)$, $\mathbf{Bx}(\lambda)$, $\mathbf{Cz}(\lambda)$ are unknown [4].

$$\bar{y}'(\lambda)=\mathbf{Ay}(\lambda) \tag{1}$$

$$\bar{x}'(\lambda)=\mathbf{Bx}(\lambda)[1-\mathbf{Ay}(\lambda)] \tag{2}$$

$$\bar{z}'(\lambda)=\mathbf{Cz}(\lambda)[1-\mathbf{Ay}(\lambda)][1-\mathbf{Bx}(\lambda)] \tag{3}$$

The spectral sensitivities of partial channels $\bar{x}'(\lambda)$, $\bar{y}'(\lambda)$, $\bar{z}'(\lambda)$ of proposed scanning system are the colour matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ (CIE 1931, 2-deg), which are corretted with respect to maximum effectivity of transmition of light flux throught the splitting system, further to maximum transparence of splitting system and also with respect to spectral sensitivities of image sensor CCD.

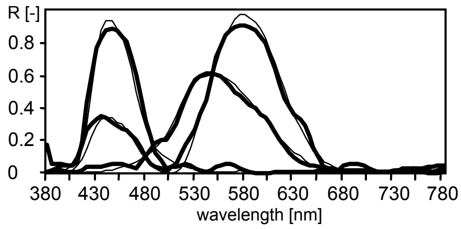

Fig. 2 Ideal spectral reflectances **Ay**(λ), **Bx**(λ), **Cz**(λ)and their approximation by real optical interference filters (approximation by real filters – bold line)

With the solution of equations (1), (2), (3), we acquire spectral reflectances of partial filters **Ay**(λ), **Bx**(λ) and **Cz**(λ). Their calculation marks the fact, that the colour splitting system is not orthogonal. It comes to this, that the curves of the spectral sensitivities of scanning system overlap one another above wavelength axis. By the separation, the light energy is sucked into two and somewhere even into three paths. The ideal spectral reflectances of partial filters of XYZ prism are

$$\mathbf{Ay}(\lambda)=\bar{y}'(\lambda) \tag{4}$$

$$\mathbf{Bx}(\lambda)=\bar{x}'(\lambda)/\left[1-\bar{y}'(\lambda)\right] \tag{5}$$

$$\mathbf{Cz}(\lambda)=\bar{z}'(\lambda)/\left[1-\bar{y}'(\lambda)-\bar{x}'(\lambda)\right] \tag{6}$$

The approximations of ideal spectral reflectances **Ay**(λ), **Bx**(λ), **Cz**(λ) by real optical interference filters (see Fig. 2) were made in programme Synopsys [5]. The technical solving of real optical interference filters consists in realization of dichroic thicknesses [6], [7], [8]. This is coating of beamy pellucid medium (e.g. boro-silicate glass BK7) with thicknesses, whose thickness is comparable with wavelength of light. The thicknesses are sorted step by step with alternating higher and lower refractive index. Filter **Ay**(λ) is set up from 8 layers of 3 materials (MgF_2, CeF_3, CeO_2), filter **Bx**(λ) is set up from 12 layers of 4 materials (MgF_2, CeF_3, CeO_2, SiO), and filter **Cz**(λ) has 12 layers of 3 materials (MgF_2, CeF_3, ZrO_2) [11].

3. The geometry of the colour splitting system XYZ

The colour splitting system *XYZ* (see Fig. 3) consists of four prisms and three interference filters. The colour splitting system constitutes a 3-band frequency selective switch of light pencils and a three-band amplitude one. The pencils generate the partial images ***X***, ***Y***, ***Z*** on the outputs of the switch. The images are scanned via 3 sensors, e.g. CCD sensors, and video signals E_X, E_Y, E_Z as electrical analogs of trichromatic components *X*, *Y*, *Z* are obtained. The prism is from glass BK7. The third prism functions only as adjusting shim for the provision of sufficient room for image sensor ***Z***. Each of prisms is proposed and in set sorted so that traces lengths of partial light tubes would be identical and prisms proportions would enable trouble-free transit of light tubes with required diameter. All 3 filters are reflective-interferential. With these filters, the rear surfaces of the first, the second and the fourth prism are coated, meant in direction of beams going. The third prism creates an adjusting shim. Filters are set up from dielectric multilayers of these materials: SiO, MgF_2, CeF_3, ZrO_2, CeO_2. The spectral reflectances of partial filters **Ay**(λ), **Bx**(λ), **Cz**(λ) are illustrated on Fig. 2. Each partial light tube executes two reflections in the XYZ prism. The first reflections of partial light tubes occur on the filters **Ay**(λ), **Bx**(λ) and **Cz**(λ). These reflections are frequency and amplitude selective. The second reflections of light tubes are total and occur on the front walls (on the glass-air passages) of the 1st, 2nd and 4th prism. After the second reflections, the partial light tubes with spectral sensitivities $\bar{y}'(\lambda)$, $\bar{x}'(\lambda)$, and $\bar{z}'(\lambda)$ respectively come to the image sensors.

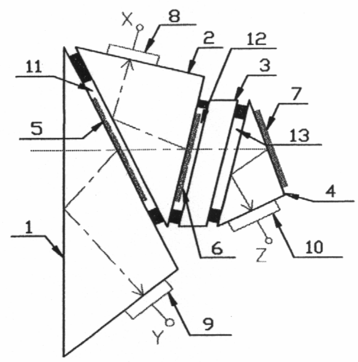

Fig. 3 The colour splitting system XYZ
1,2,3,4- glass prisms; 5,6,7 – dielectric multilayers (filters); 8,9,10 – image sensors; 11,12,13 – air interspaces

From the XYZ prism transmissivity, from the summing curve of spectral sensitivities $\bar{x}'(\lambda)+\bar{y}'(\lambda)+\bar{z}'(\lambda)$ (see Fig. 4), results that only a part of incident light spectrum is used to obtain trichromatic components *X*, *Y*, *Z* (partial images ***X***, ***Y***, ***Z***). Unused light spectrum, mainly the section from surroundings of wavelength 500nm, passes through filter **Cz**(λ)and quits the XYZ prism. This light is required to be absorbed in the camera (e.g. absorption with velvet) to prevent its reflecting back into the prism. Otherwise this light would cause spurious artefacts in the picture during reproduction.

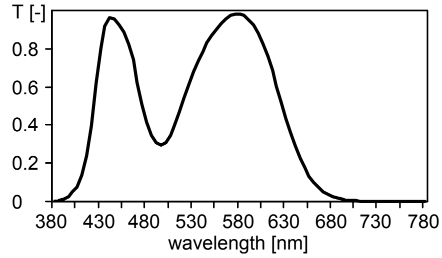

Fig. 4 The XYZ prism transmissivity
summing curve of spectral sensitivities $\bar{x}'(\lambda)+\bar{y}'(\lambda)+\bar{z}'(\lambda)$

To create the glass-air passages alias total reflections also for components X and Z, there has to be a slim air interspace 0.1 - 0.2 mm between each two prisms. This air interspace is also between the second and the third prism. It does not engender total reflection, but air interspace has favourable effect on layers number and materials kinds of filter $\mathbf{Bx}(\lambda)$. In other words, the filters impedance match will be less demanding, if the substance with different impedance is from every filter side.

4. The colorimetric distortion of the colour splitting system XYZ

The criterium of the success of colour splitting system solving is final colour distortion. The quantity JND - Just Noticeable Difference was chosen as criterium of colour distortion [9]. To assesment of colorimetric distortion, 12 colour testing samples were used. The attained spectral sensitivities of XYZ prism, for which the colorimetric distortion was determined, were counted from the proposed (approximative) reflectances of partial filters based on (1), (2), (3). The mean value of final colorimetric distortion from used file of colour testing samples is

$$\overline{\mathrm{N}}_{XYZ} = 2.87 \text{ jnd.}$$

In result, influence of brightness differences is included. Coordinates u, v of each original and reproductive colour samples are shown in CIEuv chromacity diagram (Fig. 5).

From the diagram follows that the proposed XYZ prism minimally distorts samples corresponding to greatly deep colours as well (samples 1–7), which lie outside of colour gamut reproduced by contemporary trichromatic display devices.

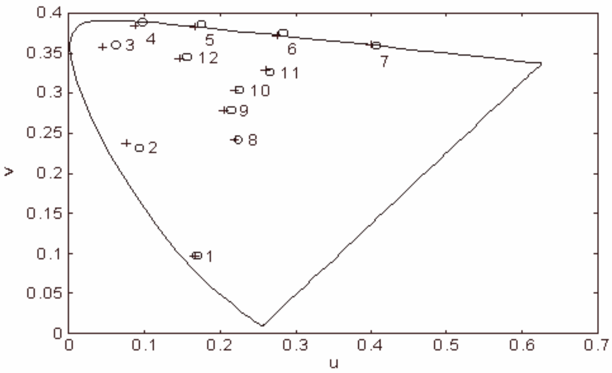

Fig. 5 The result of colorimetric distortion test in CIEuv chromacity diagram. Daggers: coordinates of original colours, wheels: coordinates of reproductive colours

5. Conclusion

This paper was to infer in what way the colorimetry of TV scanning set could proceed to the fully exploitation of the new colorimetric different display devices. Colour splitting system *XYZ* evades irremovable difficulties during optical separation of partial components (known in classic scanning system RGB) hereat, that its ideal spectral sensitivities are, in contrast to the ideal spectral sensitivities of classic scanning system, only positive. Hence, there is no need to introduce additional corrections for areas with negative spectral sensitivities of partial channels as in classic scanning system. All three filters in the XYZ prism are of the reflective-interferential type, contrary to the green filter of RGB prism, which is coloured and therefore absorptive. The colorimetric system of primary lights **X**, **Y**, **Z** overlays the whole gamut of existing colours. For the light of an arbitrary colour, the trichromatic components X, Y, Z are only positive. The final effect is that the colour gamut of reproduction will not be reduced [10], [11].

Acknowledgement

The colour splitting system *XYZ* for TV cameras was handed by Emil Košťál, Jan Kaiser, and Jiří Slavík as a utility model and patent application [12]. The registration certificate of utility model was granted on 29.5.2000. Number of the utility model is 10026. The certificate of patent registration was granted on 19.4.2001. Number of the patent is 288456.

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