aic 2009
sydney

The Colour Society of Australia Inc.

AIC 2009

Proceedings of the 11th Congress of the International Colour Association

Sydney, Australia
27 September to 2 October 2009

LCTF SPECTRAL PARAMETERS STABILITY

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ABSTRACT

Liquid crystal tunable filters (LCTF) are being widely used as spectral analysis system in different applications, particularly in color imaging and multispectral imaging. This work presents a study on the stability, at short and long terms, of the parameters defining the bandpass function: spectral distribution of transmittance maximum, bandwidth and mean or effective wavelength, λ_m, calculated according to the Full Wide Half Maximum (FWHM) criterion. Measurements have been made by a direct method, (tuning the filter at one wavelength and recording the spectral transmittance) along the full spectral range (FSR), using a high quality spectrophotometer.

Keywords: liquid crystal tunable filter, bandpass function, multispectral imaging.

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INTRODUCTION

Multispectral imaging systems and techniques have become powerful tools for the rapid measurement of high-spatial-resolution spectral images. They allow us to recover -at every pixel of the image- the spectral radiance of an illuminant, the reflectance of an object or the combined color signal. Liquid crystal tunable filters (LCTF) attached to a monochrome CCD camera are being widely used as spectral analysis system in multispectral imaging.[1-5]. In many cases they are used to obtain the effective spectral distribution of a source according to the equation:

$$L_\lambda(x,y,\lambda_0)=\frac{S(x,y,\Delta\lambda,\lambda_0)}{\int_{\Delta\lambda}\tau(\lambda_0,\lambda)\cdot R(x,y,\lambda)\cdot d\lambda} \qquad (1)$$

Where S is the system response, τ is the LCTF transmittance over the spectral bandpass (the bandpass function hereafter), R is the system's responsivity, λ_0 is the wavelength to which the spectral system is tuned at and $\Delta\lambda$ is the width of the spectral pass-band. Then uncertainty and resolution of L_λ mainly depend on that of system's responsivity as well as on that of LCTF bandpass function.

In a previous work, these authors have shown the necessity of individually measuring LCTF bandpass function, since data provided by the manufacturer have not got enough resolution to perform low uncertainty radiometric measurements. In addition they have shown that the bandpass function has to be determined by the direct method (what realises the definition) [6].

This work presents a study on the stability, at short and long terms, of the parameters defining the bandpass function: spectral distribution of transmittance maximum, bandwidth and mean or effective wavelength, λ_m, calculated according to the Full Wide Half Maximum (FWHM) criterion.

EXPERIMENTAL MEASUREMENTS AND RESULTS

The LCTF used for the purposes of this work was manufactured by Cambridge Research & Instrumentation, Inc. (CRI) with the following specifications:7 nmnominal bandwidth (FWHM), 35 mm clear aperture, 400 nm-720 nm spectral range, and 0.01% average out-of-band transmittance. This device consists of a Lyot filter in conjunction with liquid crystal variable retarders, which allow to select the transmittance peak within the operating wavelength range.Nematic liquid crystals can work as electronically adjustable phase retarders. This feature permits to achieve a continuous range of retardance values (Δn can be changed by modifying the voltage applied to the liquid crystal), thus leading to continuous wavelength tuning. The transmittance of the filter is the product of the transmittances of the individual stages.

We have carried out bandpass function measurements by a direct method, (tuning the filter at one wavelength and recording the spectral transmittance) along the FSR, using a high quality spectrophotometer. The spectrophotometer's bandwidth was fixed at 0.5 nm and a linear polarizer was introduced to keep a constant polarisation state along the FSR.

Repeatability (series of measurement without realignment of the filter), as well as reproducibility (realignment between measurements) have been checked. Series of measurements were initially performed during the year 2007 and then repeated in 2009. Furthermore, in 2009, sequential measurements, turning off and on the filter, in order to study its possible effect over the tuned wavelength, have also been made.

Transmittance

Figure 1 shows the measured bandpass function at some wavelengths, at the time of year 2007. Really the bandpass function was determined by tuning the LCTF at every nanometer along the FSR. The results showed that the maximum passband transmittance decreases as the wavelength does, although not monotonically, having different local minima along the FSR. For simplicity we have shown only those wavelengths where local minima were found.

Measurements repeated on year 2009, have shown the same behaviour at the same wavelengths. No dependence of the spectral distribution of transmittance have been observed with the process of switching off and on.

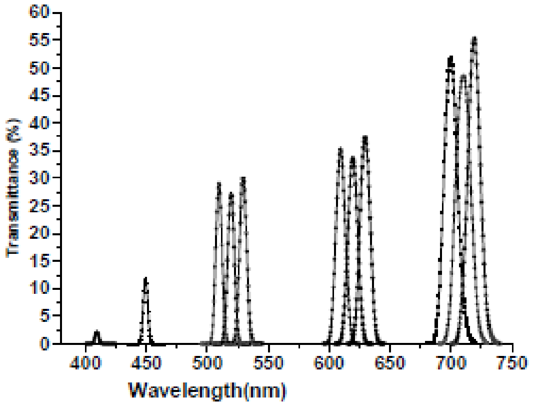

Fig 1. Passband function of the LCTF at some nominal wavelengths

Bandwidth

Next analysed parameter was the bandwidth calculated according to the FWHM criterion. Figure 2 shows the results obtained in relation to the nominal tuned wavelength, λ_s, along the different series of measurements recorded. As it can be seen the bandwidth increases almost linearly with λ_s, and no differences have been found between 2007 and 2009.

As in the case of the spectral transmittance, no dependence with the re-alignment of the filter has been observed.

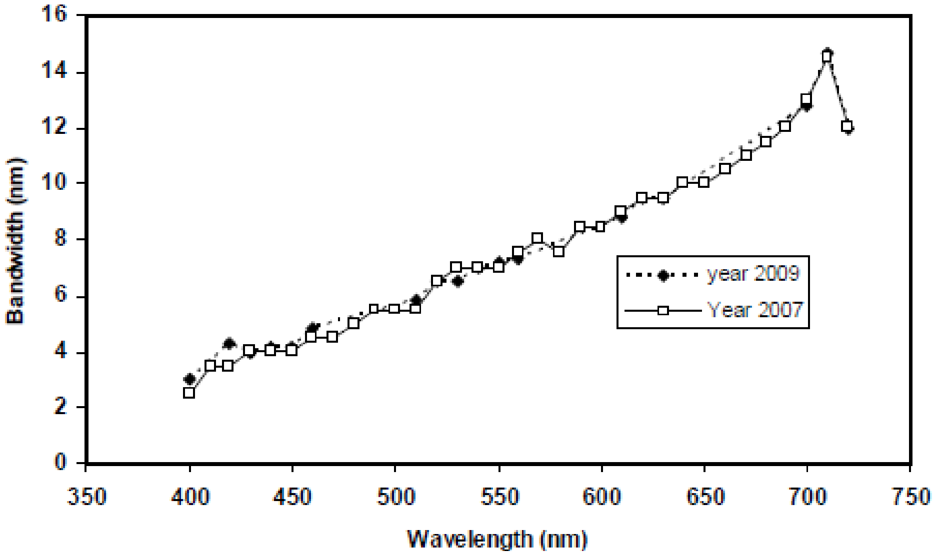

Fig 2. Spectral distribution of the measured bandwidth in 2007 and 2009

Mean or effective wavelength

Finally results obtained on the mean or effective wavelength, λ_m, and differences with the nominal tuned wavelength, λ_s have been studied. Figure 3 shows the averaged results obtained along the different series of measurements recorded. Oscillations around a central (non null) value have been observed and differences between the mean wavelength and the nominal tuned wavelength as large as 1,5 nm have been found.

In this case it has to be also enhanced that, differences greater than the uncertainty of the measurements have been observed related to a non very careful re-alignment. Therefore, these results seem to infer an increase in the uncertainty of use in wavelength when using this kind of filter as spectral analysis systems.

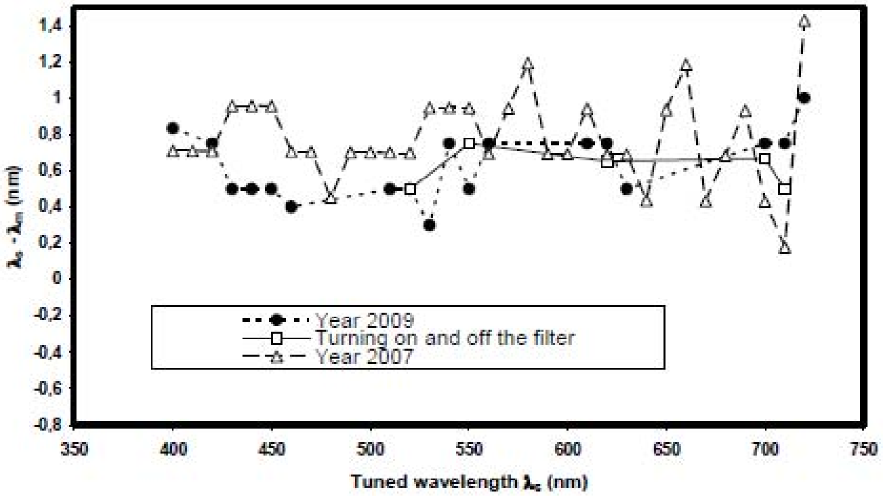

Fig 3. Spectral distribution of the differences obtained between mean wavelength measured (FWHM criteria), λ_m, and the actual tuned wavelength, λ_s, in different moments and switching off and on the filter controller.

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