1. INTRODUCTION

Liquid crystal tunable filters (LCTF) attached to a monochrome CCD camera are being widely used as spectral analysis systems in multispectral imaging. In many cases they are used to obtain the effective spectral distribution of a source according to the equation:

\[ T(\lambda) = \frac{L_{\text{out}}}{L_{\text{in}}} = \frac{1}{1 + \left(\frac{\lambda - \lambda_0}{\Delta \lambda}\right)^2} \]

Where \( S \) is the system response, \( \gamma \) is the LCTF transmittance over the spectral bandpass (the bandpass function hereafter), \( R \) is the system’s responsivity, \( \lambda_0 \) 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 \( L_{\text{out}} \) mainly depend on that of system’s responsivity as well as on that of LCTF bandpass function.

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, \( \lambda_{\text{med}} \), calculated according to the Full Width Half Maximum (FWHM) criterion.

2. EXPERIMENTAL MEASUREMENTS

The LCTF of this purpose was developed by Cambridge Research & Instrumentation, Inc. (CRI) with the following specifications: 7 nm nominal bandwidth (FWHM), 35 nm clear aperture, 405 nm to 720 nm spectral range, and 0.01% average out-of-band transmittance. This device consists of a Lyot filter in conjunction with variable liquid crystal 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 (\( \gamma \) 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 polarization state along the FSR.

Repeatability, as well as reproducibility have been checked. Series of measurements were initially performed during the year 2007 and then repeated in 2009. Furthermore, in 2009, sequential measurements, turning on and off the filter, in order to study its possible effect over the tuned wavelength, have also been made.

TRANSMITTANCE RESULTS

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.

BANDWIDTH RESULTS

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, \( \lambda_{\text{med}} \), along the different series of measurements recorded. As it can be seen the bandwidth increases almost linearly with \( \lambda_{\text{med}} \) 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.

MEAN OR EFFECTIVE WAVELENGTH RESULTS

Finally results obtained on the mean or effective wavelength, \( \lambda_{\text{med}} \), and differences with the nominal tuned wavelength, \( \lambda_0 \), 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.

3. CONCLUSIONS

• Spectral distribution of transmittance maximum and passband function seems to be stable along time within the measurement uncertainty.

• The difference between the effective wavelength and the tuned one seems to be less stable. Changes have been found from measurements in 2008 and 2009. The wavelength uncertainty of use has to be considered when using these filters.

Fig 1: LCTF Passband function at some wavelength

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

Fig 3: Spectral distribution of the differences obtained between mean wavelength measured (FWHM criterion), \( \lambda_{\text{med}} \), and the actual tuned wavelength, \( \lambda_0 \), in different moments and switching off and on the filter controller.