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Colour Sensor White Balance Influence on White-Light Interferometer Resolution

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Abstract

Impact of a sensor color balance on white-light full-field optical coherence tomography (FF-OCT) resolution is investigated in the paper. Full width at half magnitude (FWHM) of a coherence pulse was calculated for various white balance (WB) settings. Simulated dependence of FWHM on WB of a sensor and experimental data are shown in the paper. The minimum interference pulse width can be achieved by the proper color balance coefficients choice. And in this case the pulse is narrower than either one registered by colour image sensor with WB based on light source emission spectrum or by monochrome image sensor.

Introduction

White-light full-field optical coherence tomography (FF-OCT) is a well-known technique for cell level tissue inner structure investigation [1-3]. The main advantage of the technique is a high spatial resolution in transverse and longitudinal directions. The latter is due to wide effective spectrum of a probing light [4, 5]. It is shown in [6] that the width of the effective spectrum is determined by impact of all components of the interferometer on a light source emission spectrum. Assuming optical elements such as mirrors, beamsplitter and microobjectives are perfect, one may consider a spectral response of a detector has a determinative influence on the effective spectrum [7].
In the work we demonstrate a possibility of summarized effective spectrum shaping by changing colour image sensor spectral response using white balance (WB) correction. A dependence of interference pulse width and white-light interferometer resolution on WB coefficients is shown. Also a possible increase of interferometric system resolution compared with one may achieved using general color correction based on the type of the source is noted.

Interference Signal Acquisition With Colour Sensor

The effective spectrum of light $\tilde{S}_D(\lambda)$ is described by an expression [6]:

$$\tilde{S}_D(\lambda) = S_D(\lambda)\cdot S_S(\lambda), \qquad (1)$$

where $S_D(\lambda)$ is the spectral sensitivity of the detector and $S_S(\lambda)$ is a light source emission spectrum. When the spectral response of each colour channel $S_R(\lambda)$, $S_G(\lambda)$ and $S_B(\lambda)$ is given, the summarized effective spectrum could be written as:

$$\tilde{S}_{RGB}(\lambda) = S_{RGB}(\lambda)\cdot S_S(\lambda) = \sum_{c=R,G,B} \tilde{S}_c(\lambda), \qquad (2)$$

where $\tilde{S}_R(\lambda)$, $\tilde{S}_G(\lambda)$ and $\tilde{S}_B(\lambda)$ are the effective spectrums of those portions of light which generate an interference patterns in the corresponding colour channel and $S_{RGB}(\lambda)$ is the summarized sensitivity spectrum of colour detector.
For take into account white-balance correction in the model we introduce weight coefficients k_c:

$$\tilde{S}^k_{RGB}(\lambda) = \sum_{c=R,G,B} k_c \tilde{S}_c(\lambda), \qquad (3)$$

where k_c is a white-balance coefficient in a color channel c, and $\tilde{S}_c(\lambda)$ is a effective spectrum of the channel.
According to the Wiener-Khintchine theorem [4] coherence function of light with the summarized effective spectrum (3) is equal to weighted sum of the partial coherence functions:

$$\Gamma_{RGB}(\Delta) = \sum_{c=R,G,B} k_c \Gamma_c(\Delta) = \\ = \sum_{c=R,G,B} k_c \int_0^\infty \frac{1}{\lambda^2} \tilde{S}_c(\lambda) e^{\frac{i2\pi\Delta}{\lambda}} d\lambda =, \qquad (4) \\ = \int_0^\infty \frac{1}{\lambda^2} \tilde{S}^k_{RGB}(\lambda) e^{\frac{i2\pi\Delta}{\lambda}} d\lambda$$

where Δ is the optical path difference, and λ is the wavelength of light, k_c is the white balance coefficient corresponding to the colour channel c, $\tilde{S}_c(\lambda)$ is the spectral response of colour channel c, $\tilde{S}_{RGB}(\lambda)$ is the summarized effective spectrum and $\Gamma_{RGB}(\Delta)$ is the summarized coherence function. White balance coefficients are taking into account in both $\tilde{S}_{RGB}(\lambda)$ and $\Gamma_{RGB}(\Delta)$.

Model of Impact of Various White Balance Correction on Interference Signal

In the paper we analyze the full width at half magnitude (FWHM) of the coherence function to estimate the impact of the white balance correction. As follows from (4) only the color balance coefficients determine a shape of the summarized coherence function for the given image sensor and light source. Therefore the coherence function width l_{RGB}^{source} is a function of three variables $l_{RGB}^{source}(k_R, k_G, k_B)$. For convenience we can fix one of coefficients ($k_G = 1$) and change the others. Therefore the interference signal width can be represented as a two variable function $l^{source}(k_R, k_G = 1, k_B)$.

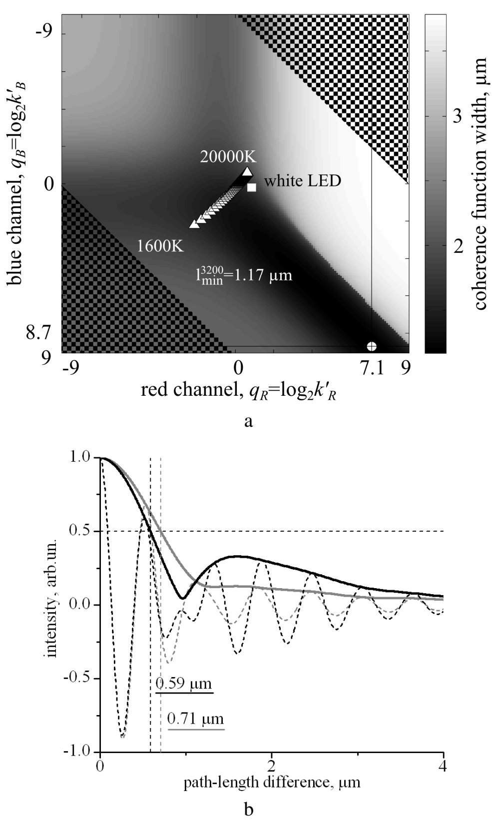

Fig. 1. The dependence of the summarized coherence function width on white balance settings for the halogen lamp (a) and the function absolute value and real part (b) of the coherence function with color correction being adjusted for white balance (gray curves) and for minimum of the coherence pulse width (black curves)

Dependence of the coherence function width l^{3200} on the white balance coefficients is shown on Fig. 1a. The data is valid for halogen lamp operating at 3200°K temperature. The triangle-marked curve indicates a set of vectors $\mathbf{k} = (k_R, k_G, k_B)$ each corresponds to WB settings based on thermal light source of various colour temperature. The square marker indicates **k** of white LED effective spectrum white balance settings. The circle points the $\mathbf{k}_{\mathbf{min}}$ values at which minimum value of the coherence function width $l_{\min}^{3200}$(k_R=$2^{7.1}$, k_G=1, k_B=$2^{8.7}$)=1.17 µm is achieved. The absolute value and the real part of the summarized coherence function of 3200K light source irradiation, registered with Sony ICX204AK image sensor and appropriate colour balance coefficients are shown on fig. 1b. The gray curves correspond to regular white balance settings and the black ones to $\mathbf{k}_{\min}$.

The summarized coherence functions widths of different sources are presented in Tab. 1. The term $l_{\min}$ stands for the minimum value of the coherence function width being achieved using Sony ICX204AK (DCU223C Thorlabs colour camera, Germany) image sensor color balance correction where the term l_{source} means the value of the coherence function width when the colour balance is adapted to comply with the light source spectrum. To compare we have also calculated FWHM l_{mono} *in* case of using monochrome image sensor Sony ICX204AL (DCU223M camera Thorlabs, Germany).

Tab. 1. The FWHM for various combinations of light source and white balance settings

Light source	FWHM of interference pulse			WB coefficients values
	$l_{\min}$	l_{source}	l_{mono}	$\log_2 k_{RGB}$
2000°K	1.27 µm	1.55 µm (18%)	1.45 µm (12%)	3.7; 0; 7.2
2800°K	1.19 µm	1.45 µm (18%)	1.31 µm (9%)	5.7; 0; 7.7
3200°K	1.17 µm	1.41 µm (17%)	1.00 µm (-17%)	7.1; 0; 8.7
WD	1.45 µm	1.66 µm (12%)	1.82 µm (20%)	5.3; 0; 4.5

Experimental results

For confirm theoretical data we make a number of experiments. We use white light Linnik type microinterferometer to obtain interference pattern. The signal was recorded by Nikon D100 DSLR camera in 12bit raw files. Next data was processed by Matlab according to the theoretical model.

Simulated and measured FWHM of interference pulse registered by D100 are shown on fig. 2. The experimental data correlate well with theoretical one instead on we did not take into account a transmission spectrum of the optical scheme in the simulation. There are also some errors since noise. But despite of this we have 10% error in the minimum pulse width which is 1.02 μm in the experiment (0.93 μm theoretically predicted).

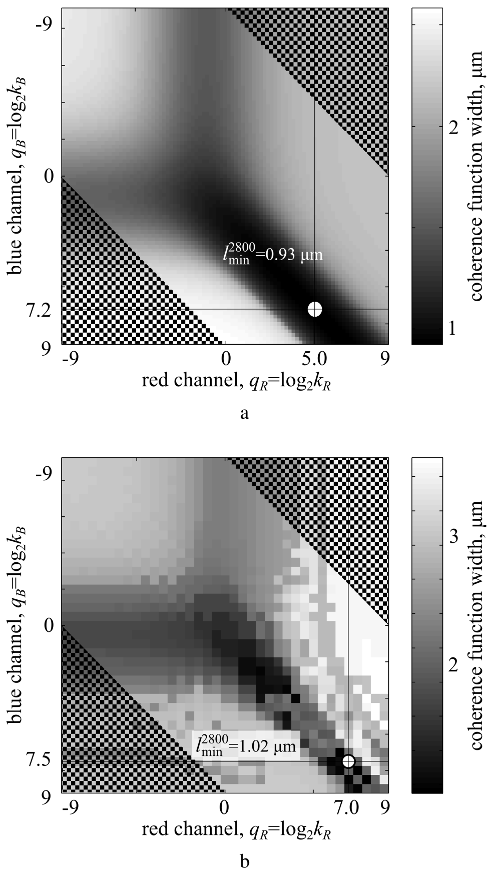

Fig. 2. The dependence of the summarized coherence function width on white balance settings for the halogen lamp light source with 2800°K, registered by Nikon D100 DSLR camera: theoretical simulation (a) and experimental data (b)

Conclusion

The results show that the minimum interference pulse width can be achieved by the proper white balance coefficients choice. And in this case the pulse is narrower than either one registered by colour image sensor with WB based on light source color temperature or by monochrome image sensor (Tab.1). In addition since the usage of colour image sensor reduces the spectral range and the restrictions on optical components quality decline as well.

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