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Speckle-Enhanced Prism Spectrometer

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***Abstract*—We present an improved prism spectrometer with high wavelength range and spectral resolution. The device is an upgraded prism spectrometer that utilizes an additional scattering medium leading to a wavelength-dependent speckle pattern. We demonstrate < 20 pm resolution and ~ 750 nm wavelength range with the proposed device. With the demonstrated spectral resolution, the speckle-enhanced prism could provide the means to image deep tissue layers in Optical Coherence Tomography.**

Keywords— Spectrometer, prism, speckle, Optical Coherence Tomography

I. INTRODUCTION

Conventional prism spectrometers offer spectral-spatial mapping, where each wavelength component is directed to a distinc position on the detector array. Although a wide spectral range is adresses, the spectral resolution is limited to ~ 1-nm with conventional optics in prism spectrometry. Grating spectrometers also provide spectral-spatial mapping with typically superior resolution to prism spectrometers, yet significantly limited in their spectral range due to overlapping of diffraction orders [1]. On the other hand, speckle spectrometers rely on mapping different wavelenghts to different speckle patterns offering unprecedented spectral resolution with limited wavelength range [2], [3].

In this study, we combine the benefits of prism and speckle spectrometers through utilizing a typical prism spectrometer architecture (offering wide spectral range) with an additional scattering layer. The prism allows for seperating speckle patterns to different locations enabling high speckle contrast as opposed to speckle spectrometers that utilize the same detector area for all spectra.

II. EXPERIMENTAL SETUP

Figure 1 illustrates the spectrometer architecture, consisting of a collimated light source (830-880 nm range), first cylindrical lens to focus the light onto the scattering medium, second cylindrical lens to re-collimate the light and third cylindrical lens to focus the light back onto the CCD camera.

The system is first calibrated with the use of a tunable light source to record the speckle patterns for each wavelength. Following the calibration routine, we place a broad-band source (super luminiscent diode:SLD) for reconstuction of the spectrum. The acquired speckle pattern: *I(x)* can be represented based on the acquired wavelength-dependent speckle patterns as [2]:

$$\boldsymbol{I(x)} = \int \boldsymbol{S(\lambda)\,T(\lambda)\,d\lambda} \qquad (1)$$

where I(x) is the position dependent intensity of the captured image for the broadband source, T(λ) is speckle patterns acquired for different wavelengths, and S(λ) represents the weights. Equation 1 can also be written in matrix form as:

$$\boldsymbol{I = T.S} \qquad (2)$$

The spectrum (weight of the speckle patterns) can be recontructed using:

$$\boldsymbol{S = T^{-1}.I} \qquad (3)$$

III. RESULTS

In this study, we share the result of a nanoparticle – epoxy mixture based scatterer, prepared through mixing TiO_2 nanoparticles: ultraviolet (UV) curable epoxy mixture with 1:12 mass ratio. The mixture was poured in between two glass slides separated by 750 µm thickness. Figure 2a illustrates the wavelength correlation function calculated between acquired speckle images, whose half-width half maximum width is considered the spectral resolution of the spectrometer. For the above-mentioned scatterer, we observe a spectral resolution of 17 pm, as showcased in Figure 2a. Furthermore, we've calculated the spectral range to be ~ 750-nm based on the ratio of CCD camera width to the line-width (FWHM) for a given wavelength. The resolution and the spectral range corresponds to a wide dynamic range of 44240. Figure 2b illustrates successful reconstruction of the SLD source with and without a 10-nm bandwidth band-pass filter placed in front.

IV. CONCLUSIONS

In this study, we presented a hybrid prism/speckle spectrometer device: where we've showcased a spectral resolution of 17pm, and a wavelength range of 750 nm. The strength of the proposed spectrometer comes from a simple and low-cost add-on, the scattering medium, on top of a conventional spectrometer. With this simple addition, the spectrometer is now able to provide two orders of magnitude improvement in the spectral resolution (17 pm vs. 1.6 nm) with identical spectral range.

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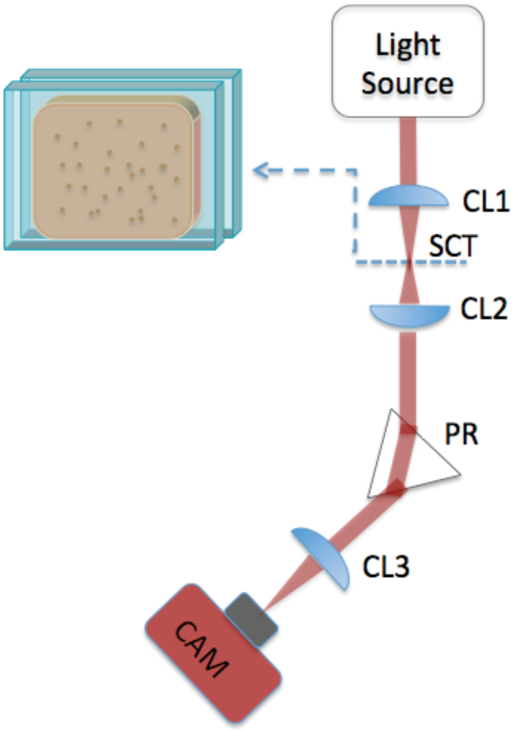

Fig. 1 Proposed spectrometer architecture, comprising a Light source, cylindrical lenses (CL1,2,3) to focus onto the scattering medium (SCT), collimate and re-focus onto the CCD camera (CAM). A prism (PR) is utilized to map speckle patterns to distinct locations on the camera.

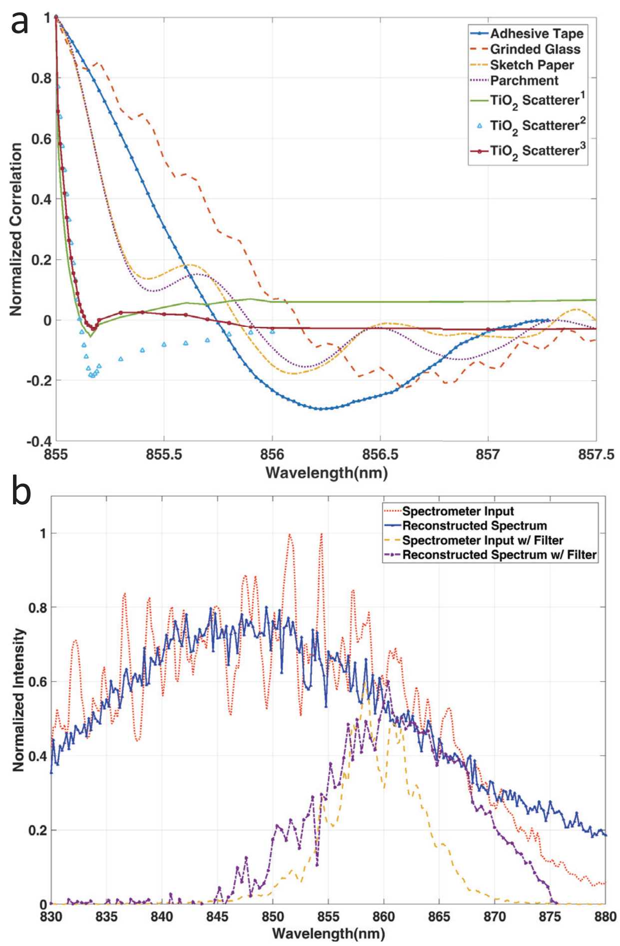

Fig. 2 Experimental results a) Correlation function achieved from a variety of scattering media. The nanoparticle-epoxy mixture mentioned in the text is labeled as TiO_2 scatterer #3 in the legend, showcasing a spectral resolution (correlation width) of 17 pm. b) Reconstruction of the SLD (with and without a band-pass filter) spectrum using SEPS and Eq3 vs. a commercial grating spectrometer.

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