High performance snapshot spectral imaging using a generalisation of a Lyot filter

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A fundamental issue for spectral imaging techniques is how to record a three-dimensional spectral data cube using two-dimensional detector arrays. Time-sequential scanning of either the wavelength or space-domain are well-established techniques, but suffer from two important drawbacks: (1) optical throughput is reduced by the time-sequential multiplexing and (2) time-sequential recording means that they are fundamentally unsuited to recording transient phenomena. We have recently reported the generalization of the traditional Lyot filter to simultaneously replicate and interferometrically spectrally filter images to form an array of narrowband images on a single detector array: the Image Replicating Imaging Spectrometer. This concept is almost alone among spectral imaging techniques, snapshot or time sequential, in offering almost perfect optical throughput (no light is rejected), no requirement for inversion (so there is no degradation in signal-to-noise ratio) and dense spatial sampling (unlike Beyer-like approaches) and almost 100% usage of detector pixels. It is however fundamental to the spectral filtering of the generalized Lyot filter that significant sidelobes exist on spectral filter functions. This can degrade both the accuracy for spectral quantification of chromophors and also image quality.

We describe here (1) the integration of an image-plane array of filter tiles into IRIS to remove the spectral sidebands and (2) achromatisation of the longitudinal chromatic aberration that plagues all broadband spectral imaging techniques. We illustrate this enhancement of IRIS using an application-specific narrow-band eight-band IRIS and a general-purpose 16-band, broadband 400-1000nm system as depicted in Fig. 1. The improvement in spectral filtering reduces the correlation between spectral bands and enhances the ability to discriminate between chromophors as illustrated by the transmission functions in Fig 2 and the improved quantification of blood oxygenation. The sidelobes in the filter function also interaction with spectral dispersion in the birefringence of the Wollaston prisms to produce image replications that are effectively removed by the introduction of the filter plate.

We will illustrate the application of the improved IRIS systems to record snapshot and video-rate spectral imaging in ophthalmic and systemic oximetry. This includes video-rate oximetry of single red blood cells, retinal vasculature, standoff oximetry of the eye and dye-free angiography.

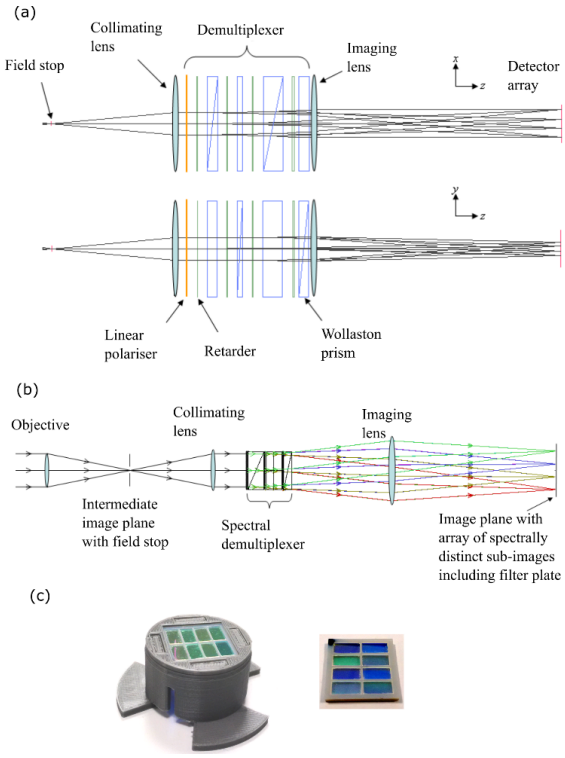

Fig. 1. IRIS optical layout for 16-band (400-1000nm) (a) and 8-band (560-600nm) systems including spectral filter plate (b). The components include the imaging system or objective, a field stop which crops the image created by the objective to avoid overlapping images at the sensor, a collimating lens, the spectral demultiplexer, the imaging lens and the camera detector array. The specifications of these optical components vary according to the objective field of view, number of wavebands, magnification and resolution required for the desired imaging application. (c) photographs of 3-D printed holder with filter plate and filter plate by itself.

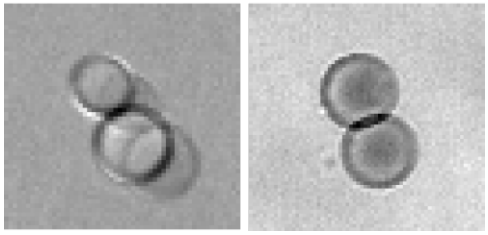

Fig. 3. Images of red blood cells recorded without (left) filter plate showing image replication and with filter plate (right) showing removal of image replications.

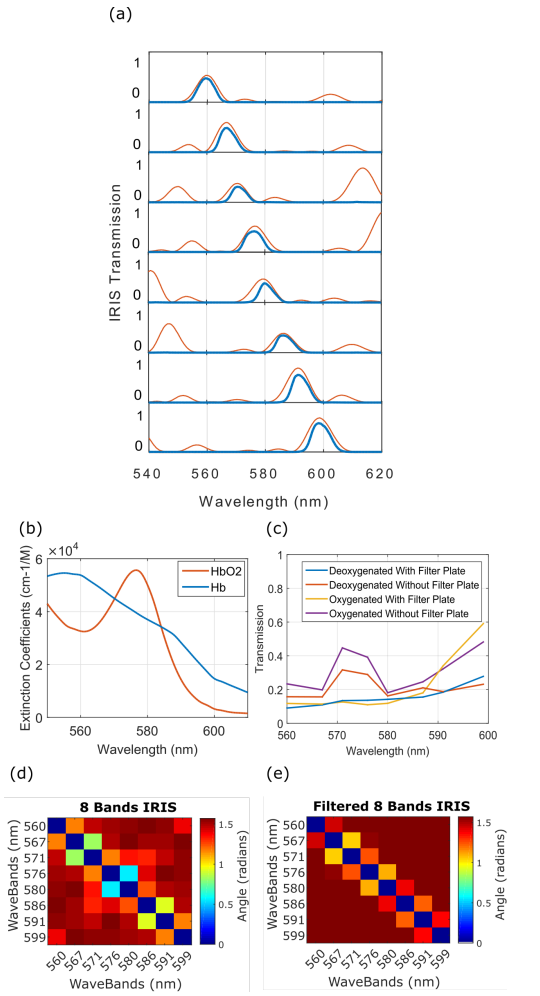

Fig. 2. (a) IRIS transmission for the 8-wavelength narrow band system, with filter plate (blue) and without filter plate (red). (b) Oxy (red) and deoxy (blue) hemoglobin extinction coefficients. (c) Transmission of 150 µm quartz capillaries filled with 0% or 100% OS blood using the filter plate (blue) and without filter plate (red). (d) Spectral angle between the 8 IRIS bands. (e) Spectral angle between the 8 IRIS bands using the filter plate.