# En Face Snapshot Spectral Imaging Of The Retina

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## Purpose

There is increasing interest in the application of spectral imaging for biochemical functional mapping of the retina. The solution to recording the required three-dimensional data cube using a two-dimensional detector array is normally to record images in time sequence in a way that scans one of the cube dimensions; typically either a sequence of narrow-band images are recorded and subsequently co-registered or a hyperspectral line image is scanned across the retina. In both cases the time sequential nature is undesirable: the increased time required to record the data combined with the infirmity that is common of patients with eye disease is problematic - both for the patient and in the impact on image quality; spectral calibration and image co-registration can be highly problematic and it is not possible to record en face time-resolved spectral images. Unfortunately a putative two-dimensional spectral camera; the spectral imaging equivalent of conventional RGB colour camera has been notable by its absence [1].

We report here on the development of a novel two-dimensional snapshot retinal camera that records a spectral data cube directly onto a conventional detector array and requires no complicated inversion algorithm to retrieve the spectral information. The snapshot capability removes the fundamental problems associated with time-sequential techniques which affect accurate blood oximetry [2, 3, 4].

## Method

The key component of this unique retinal camera is a novel *image replicating imaging spectrometer* (IRIS) that employs polarising interferometry and Wollaston prism polarising beam splitters to simultaneously replicate images of the retina in multiple spectral bands onto a single detector array [5, 6], See Fig. 1. N Wollaston prisms and N retarders produce $2^N$ replicated spectral images. In principle the technique is 100% optically efficient enabling the intensity of light at the retina to be minimised. An unusual aspect of IRIS is that the spectral transmission bands are not quite orthogonal in spectral space, but this issue is not significant relative to the high signal-to-noise ratio and snapshot characteristic.

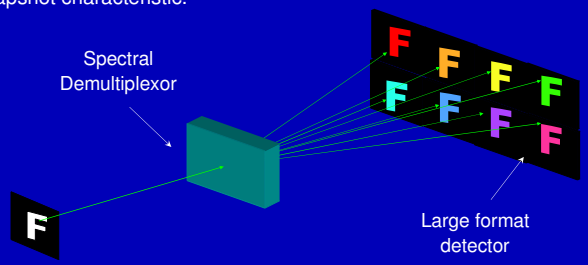


*Fig. 1. Functioning principles of an 8-band image replicating spectrometer.*

An assembled, 8-band IRIS system integrated into a *Discam* fundus camera [7] is shown in Fig. 2. The integration of IRIS system into any fundus camera is a straightforward process: the input object plane of IRIS is located at the output image plane of the retinal imager; thus the output image is replicated onto the CCD detector array.


*Fig. 2. 8-band IRIS system integrated into Discam retinal camera.*

IRIS transmission bands may be optimised for operation in specific spectral regions; we report here on optimisation for the spectral bands appropriate to blood oximetry. Previous research [3-6] has shown that an appropriate spectral window for blood oximetry occurs from 560nm to 600nm. Also, the blood's extinction coefficient experiences the maximum variations with oxygenation and two isobestic points (desirable in the physical model that yields a value for oxygen concentration).

For comparison, two IRIS systems have been assembled to optimally measure blood oxygenation; operating in the rannges 560nm to 600nm and 577nm to 600nm. The transmission bands modulated by spectral blood-transmission are shown in Fig.3. Note that some bands are optimised to maximise the spectral separation between oxygenated and deoxygenated blood, others produce retinal images practically insensitive to oxygen saturation (isobestic bands).

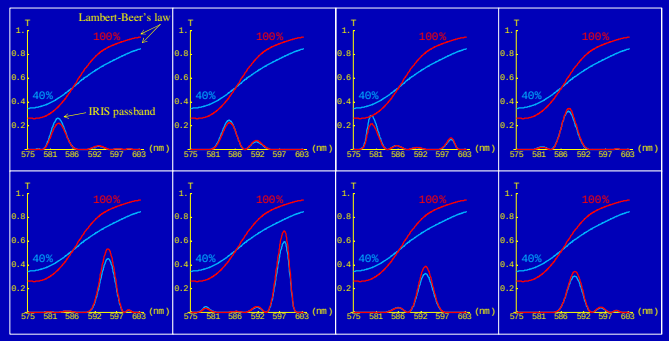


*Fig. 3. IRIS passbands as a function of oxygen saturation (red, 100%; and blue, 40%) for a 100μm vessel and modulated by Lambert-Beer's law. Note the isobestic point at 586nm and its associated passbands.*

## Results

A proof-of-concept demonstration using a pre-existing IRIS system is shown in Fig. 4, in which eight replicated narrow-band images were recorded in a single snapshot. The variations of the grey levels are due to the spectral filtering functions of the IRIS system. Notice the clear discrimination between veins and arteries although better discrimination is expected as a result of the optimisation process described above.

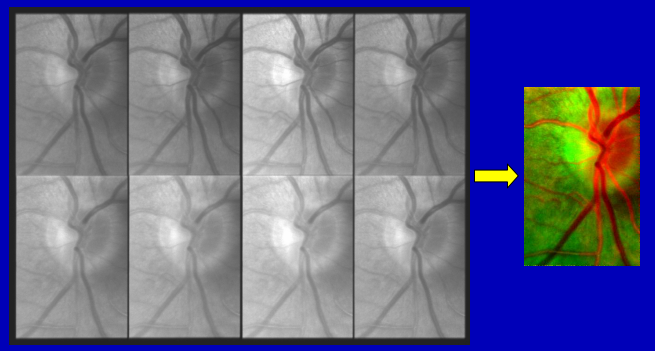

*Fig. 4. Replicated spectral images of the retina at the detector plane of IRIS.*

## Conclusions

We have described a new retinal imaging instrument for research and clinical application that provides multiple spectral images in a single snapshot. The shape and number of IRIS spectral bands can be optimised for specific applications such as snapshot oximetry. The spectral retinal data required for this optimisation can be obtained by a time-sequential random access technique such as we describe in [3,4]. The resulting optimised snapshot spectral retinal imager will enable enhanced biochemical measurements in the retina by eradicating calibration and misregistration problems associated with time-sequential techniques and the snapshot function is particularly valuable in a clinical setting.

### References

1. A notable exception is W. R. Johnson et al. "Snapshot hyperspectral imaging in ophthalmology", J. Biomed. Opt. Vol. 12 (2007)
2. A. R. Harvey et al., "Spectral imaging of the rat", ARVO 3844-B585 (2007).
3. D. J. Mordant et al., "Hyperspectral imaging of the human retina - Oximetric studies", ARVO 148-B257 (2007).
4. I. Alabboud et. al, "Quantitative spectral imaging of the retina", ARVO 2581-B658 (2007).
5. A. R. Harvey et al., "Spectral imaging of the retina", SPIE Vol. 6047 (2006).
6. A. R. Harvey et al., "Spectral imaging in a snapshot" SPIE Vol. 5694 (2005).
7. *Discam*, stereoscopic optic disc camera from Marcher Enterprises Ltd. (UK).

Commercial relationship: *Alcon, Allergan, MSD, Pfizer. **QinetiQ.