COMPRESSED FULL-FIELD FOURIER-TRANSFORM SPECTROMETRY

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Imaging Fourier transform spectrometry (IFTS) can be used for hyperspectral imaging in the wide-field mode. Wide-field hyperspectral imaging is a powerful technique for quantifying functional and morphological states of cells and tissues. Multiplexed fluoresce imaging, Multicolor spectral karyotyping of human chromosomes, spectral fluorescence resonance energy transfer(sp-FRET) and spontaneous Raman imaging are few examples. Unlike other hyperspectral imaging modalities, IFTS measures the Fourier transform of the spectrum of light at each pixel in the wide-field image, and traditionally, the inverse Fourier transform is used to extract the spectral information. The spectral recovery process (for each pixel) can be captured by a set of liner equations
written in the matrix form below.

$$I = (1+DFT) \ S + n$$

Here Interferogram, I, is the measurement vector, DFT is the discrete Fourier transform matrix, S is the spectral vector of the pixel and n is the measurement noise vector. Representing $(1+DFT)$ as a measurement matrix A, the above can be rewritten as an optimization problem of estimating S from the observations I.

$$I = AS + n$$

According to the compressive sensing theory, since A is maximally incoherent [1], when the spectral vector S is sparse or compressible, I can be incompletely or compressively sampled [1]. Therefore, for wide-field hyperspectral imaging, IFTS uniquely offers compressive data acquisition capabilities in the spectral dimension.

However due to the limitations of the existing imaging interferometers this idea cannot be implemented in wide-field mode. Michelson interferometer is non-common-path and less stable and the stable common-path Sagnac interferometer is limited in the field of view due its phase tilt. Overcoming these limitations, in this work, we introduce a new common-path and full-field imaging interferometer that can take advantage of compressive sampling. The instrument's phase stability is experimentally validated and hyperspectral imaging is demonstrated by measuring a laser line, broadband LED light sources, Fluorescent beads, fluorescently labeled cells and tissues, and Raman imaging of 4-acetamidophenol (active ingredients of Tylenol). Compressive sampling capability of the instrument is demonstrated in two applications namely, multiplexed fluoresce imaging and compressed Raman imaging.

In the fluorescence domain, we first simulate a compressive data acquisition scheme for a set of quantum dots. We evaluate the expected system performance to measure the peak-emission wavelengths of spectra in order to identify the multiplexed species. Then we demonstrate the same in an experiment to measure the peak-emission wavelengths of a fluorescent beads sample and of a mouse muscle tissue specimen with multiple species. Up to 20 times compression is demonstrated in the beads sample and up to 5 times compression is demonstrated in the tissue specimen. In the Raman domain, we experimentally demonstrate up to 10 times compression for a 4-acetamidophenol specimen.

In summary, we introduce a new imaging interferometer for compressed wide-field Fourier transform spectrometry and the instrument is about an order of magnitude faster than the state of the art IFTS systems for fluorescence and Raman applications.

References

[1] Candes, E. J., & Wakin, M. B. (2008). An introduction to compressive sampling. *IEEE signal processing magazine,* 25(2), 21-30.