Accelerated hyperspectral imaging via temporal compressive sensing

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Hyperspectral imaging (HSI), with the unique capability to discriminate various components by spatiospectral resolvability, is a powerful tool for observation and inspection, which has been applied in numerous fields, ranging from remote sensing,[1] archaeology,[2] food safety,[3] and forensic medicine,[4] to pharmaceutical research[5] and clinical diagnosis.[6] To acquire three-dimensional (3D) information $I(x, y, \lambda)$ with two-dimensional spatial and spectral dimensions, various HSI strategies have been proposed,[7] including point-scanning, wavelength-scanning, filtering-based, and snapshot methods. However, due to the lack of sensitive image sensors in the infrared region, the latter three strategies are difficult to work for HSI of infrared scenes with low signal-to-noise ratio. Moreover, for the detection of nonlinear signals, for example, with stimulated Raman scattering (SRS) and coherent anti-Stokes Raman scattering (CARS), high optical intensity is required to excite the sample, but wide-field strategies can barely provide uniform excitation and sufficient excitation power. Therefore, the point-scanning strategy is preferred for HSI of nonlinear scenes. Nevertheless, the imaging speed of point-scanning HSI is seriously limited, due to the large amounts of spatiospectral data and a single detector. The speed limitation hampers further applications of nonlinear HSI, especially for *in vivo* biomedical imaging.

As reported recently in *Advanced Photonics Nexus*, a group led by Kotaro Hiramatsu from University of Tokyo proposed a framework to improve the spectral image acquisition rate of HSI by integrating time-domain HSI and compressed sensing.[8] Instead of measuring the spatiospectral information $I(x, y, \lambda)$ directly, they choose to record the spatiotemporal information $I(x, y, \tau)$ with sparse sampling and then recover the corresponding spatiospectral information by solving an ill-posed inverse problem, as shown in Fig. 1. To verify the feasibility of the framework, a compressive sensing-based Fourier-transform CARS imaging system is designed to acquire the 3D information of the sample, where molecular vibrations are coherently excited by a pump pulse and interrogated by a time-delayed probe pulse.[9] The pump–probe pulse pairs are generated by a Michaelson interferometer, where the optical path length of one of the arms is modulated by a resonant scanner. The incident beams are spatially scanned by the two galvanometric scanners for interrogating different spatial points of the sample. With all these designs, the time-domain interferograms are sampled sparsely by utilizing 3D Lissajous scanning with triangular and sinusoidal functions to boost the hyperspectral image acquisition rate, respectively.[10] The hyperspectral images are then reconstructed by solving the inverse problem regularized with spatiospectral total variation. Hyperspectral image acquisition at a rate of 25 frames per second with a resolution of 100 pixels × 100 pixels under experimentally feasible conditions was demonstrated, which is 10 times higher than that of the previous record.

Exploiting the mapping between the temporal and spectral information by Fourier transform, sparse sampling in the temporal domain can be utilized to extract the corresponding spectral signal. By incorporating compressive sensing in temporal domain into hyperspectral imaging, an accelerated hyperspectral imaging framework is achieved. Hyperspectral images with high fidelity can be recovered by a posterior reconstruction algorithm with the spatiospectral total variation priors. This work provides a new perspective for information acquisition in hyperspectral imaging, and offers a feasible strategy to greatly accelerate 3D signal acquisition. The proposed method can also be further extended to other time-domain HSI methods, such as Fourier transform infrared and Fourier transform two-photon imaging. What's more, 4D information acquisition $I(x, y, \lambda, \tau)$ energized by compressive sensing can be expected in future based on this work.

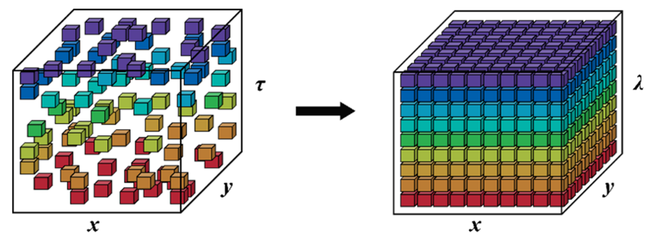

Fig. 1 Schematic of hyperspectral imaging by compressive sensing in the temporal domain. Black arrow indicates the reconstruction from sparsely sampled spatiotemporal data to hyperspectral images.

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