Reconstruction of multispectral image cubes from multiple-telescope array Fourier transform imaging spectrometer

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Abstract: Multiple-telescope arrays can function as Fourier transform imaging spectrometers, using the subaperture path-delay elements. However, the resulting spectral images are missing low spatial-frequency content. Reconstruction results are presented for a cube of simulated data using a nonlinear derivative-based sharpness metric that is designed for specific types of imagery.
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1. Introduction

In a multiple-telescope array (MTA), light is collected by a number of relatively small-aperture telescopes and imaged to a common plane in such a way that the resolution is equivalent to that of a large-aperture monolithic telescope. One condition for achieving this resolution is that the optical path lengths through each subaperture (an individual telescope in the array) are equal. In practice, these optical path lengths are controlled by path-delay elements associated with each subaperture. These elements can be used to introduce intentional path-delays between subapertures and perform Fourier transform spectroscopy. Kendrick *et al.* [1] demonstrated this technique with a two-aperture telescope and a scene of point sources. However, the spatial transfer functions for the resulting spectral images vanish in some finite region around the DC spatial frequency for a system with physically separated subapertures [2]. Thus, the problem of imaging extended objects is more difficult, since the multispectral image cube is missing low spatial frequency information.

2. Research

In general, a nonlinear algorithm is required for the reconstruction of the missing data. We have achieved promising results by maximizing a derivative-based sharpness metric subject to data-consistency and prior knowledge constraints, *i.e.*, the object spectral density must be real-valued and non-negative. This metric was designed for scenes containing regions that are fairly uniform in the spatial dimensions, such as an aerial view of an urban environment. In a band-by-band reconstruction [3], the metric successfully filled in the missing low spatial frequency content for a scene of uniform rectangular objects. These results only used spectral information derived from the intensity measurements. However, the raw measurements contain polychromatic low-spatial frequency data that is absent from the spectral data. The polychromatic measurements can be used to formulate an additional constraint on the reconstruction, but the multispectral image cube must be processed simultaneously as a whole in order to incorporate this new constraint. Such a polychromatic data constraint will set a limitation on the low spatial frequency content that is filled in by the sharpness metric. A simultaneous reconstruction also allows us to impose an energy conservation requirement on the cube as a whole. These additional constraints should yield more accurate reconstructions. We will present results for the simultaneous reconstruction of a multispectral image cube using simulated data. The results of the image reconstruction are highly dependent on the configuration of the telescope array during data collection, *i.e.*, which telescopes have path-delays and which do not.

3. References

[1] R. L. Kendrick, E. H. Smith, and A. L. Duncan, "Imaging Fourier transform spectrometry with a Fizeau interferometer, in Interferometry in Space, M. Shao, ed., Proc. SPIE 4852, 657-662 (2003).
[2] S. T. Thurman, J. R. Fienup, and R. L. Kendrick, "Imaging Fourier transform spectroscopy with multi-aperture telescopes," presented at Frontiers in Optics, Tucson, Arizona, 5-9 Oct. 2003.
[3] S. T. Thurman and J. R. Fienup, "Fourier transform imaging spectroscopy with a segmented-aperture telescope or multiple-telescope array: band-by-band image reconstruction," to be presented at the SPIE symposium Optical, Infrared, and Millimeter Space Telescopes, Glasgow, United Kingdom, 21-25 June 2004.