Remote Sensing with Hyperspectral Imagery using DASI - An Imaging Interferometer

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Abstract -- We describe an approach to terrestrial remote sensing using a novel technique, imaging interferometry. A practical implementation of the instrument, the Digital Array Scanned Interferometer (DASI), has been under development at our laboratories. An overview of recent terrestrial scenes measured using an airborne DASI sensor is presented.

INTRODUCTION

Hyperspectral imagery (spatial imagery with many contiguous spectral bands over an extended spectral range) is a promising yet underdeveloped remote sensing technique. Although the motivation for obtaining such high spectral resolution images to study the terrestrial environment has been high, imaging spectrometry is a relatively new field [1]. Progress on instrumentation and analysis techniques has occurred only recently with the advent of instruments such as AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) [2]. These developments have been spurred by recent advances in solid state detector array technology, particularly for infrared detection.

The established imaging spectrometers to date have been based on spectral dispersion, using a grating or prism to achieve spectral resolution. They have tended to be large, complex, and expensive relative to standard imaging instruments and non-imaging spectrometers. These undesirable characteristics have stemmed from fundamental optical design constraints when consideration was made of performance requirements for spectral and spatial resolution and coverage,

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signal sensitivity, signal-to-noise, and calibration accuracy.

Because of the limitations of conventional sensor technologies there has been considerable motivation to develop new technologies to improve imaging spectrometer remote sensing capabilities and adaptability to surface, aircraft, and spacecraft platforms. NASA Ames and Washington University have been developing and applying a new instrument concept, the digital array scanned interferometer (DASI), for ground and airborne-based spectral imaging. The DASI achieves spectral discrimination using two-beam interference rather than dispersion. DASIs have many of the positive characteristics associated with Fourier transform spectrometers and also the capability for spatial imaging. Perhaps one of the most notable features of DASIs is their ability to acquire an entire interferogram simultaneously without any moving optical elements, enabling the observation of rapidly changing signals within the instrument's field-of-view. (This feature is analogous to push-broom type dispersion spectrometers that acquire all spectral components simultaneously). The compactness, simplicity of design and operation, and low cost of DASIs make them particularly suitable candidates for airborne and spaceborne platform based remote sensing instruments.

References [3] and [4] describe he basic concept of digital array scanned interferometry (DASI). The principle of DASI operation is similar to that of scanned interferometers. Detected signals result from two-beam interference. Spectra are obtained by Fourier transforming these recorded interferograms. Unlike conventional interferometers, the DASI operates with its optics fixed in position. Interferograms are resolved spatially in one dimension at the detector plane by a detector array. Spatial information is available in the orthogonal dimension. Two-dimensional spatial images are obtained by scanning over a scene in a push-broom manner.

RESULTS

During 1994 and 1995, observations were made using a nadir viewing DASI prototype sensor flown aboard the NASA C-130 aircraft. The characteristics of this sensor are given in Table 1. This sensor utilized a two-dimensional short-

Table 1 - DASI imaging spectrometer specifications

A. March 1994 C-130 flights

Instrument configuration	
Principle of operation	Imaging spectrometer based on interferometry: fringes are resolved spatially
Image acquisition	Push-broom (line-by-line)
Type of data	Spectral images (2 dimensional spatial with a spectrum associated with each pixel)
Detector	NICMOS short wavelength MCT 256 × 256 array, 4 Hz maximum frame rate
Size	Core optics: 30 cm length × 10 cm height × 10 cm width; Collector lens ϕ = 1 cm
Spectral characteristics	
Range	4550 - 9090 cm^{-1} (1.1 - 2.2 μm)
Resolution	266 cm^{-1} (60 nm at 6670 cm^{-1} or 1.5 μm (mid-band))
Bands	17 contiguous resolution elements (sampling interval is selected numerically)
Spatial characteristics	
Full field of view (FOV) cross track	7.7 degrees, 256 pixels
Single pixel IFOV cross track	0.03 degrees or 0.53 mrad
Cross track coverage / resolution	0.61 km / 2.4 m for typical flight altitude of 4.6 km
Long track coverage / resolution	3.1 km / 31 m for typical flight velocity of 124 m/s
Signal-to Noise	80:1 at peak spectral intensity

B. March 1995 C-130 flights

Instrument configuration - same as above	
Spectral characteristics	
Range	4550 - 12500 cm^{-1} (0.8 - 2.2 μm)
Resolution	250 cm^{-1} (36 nm at 8330 cm^{-1} or 1.2 μm (mid-band)) - double sided interferograms 150 cm^{-1} (22 nm at 8330 cm^{-1} or 1.2 μm (mid-band)) - single sided interferograms
Bands	32 contiguous resolution elements (double sided), 53 (single sided)
Spatial characteristics	
Full field of view (FOV) cross track	25 degrees, 256 pixels
Single pixel IFOV cross track	0.1 degrees or 1.7 mrad
Cross track coverage / resolution	2 km / 8 m for typical flight altitude of 4.6 km
Long track coverage / resolution	5 km / 25 m for typical flight velocity of 100 m/s, 200 lines acquired
Signal-to Noise	Estimated 100:1 at peak spectral intensity

Table 2
Regions studied using DASI sensor from the NASA C-130 aircraft

Scene date and descriptions	scene size: cross track	along track
<u>3/94</u>		
Crow's Landing Airfield, San Joaquin Valley, CA	0.6 km	3.1 km
Miscellaneous agricultural fields, San Joaquin Valley, CA	0.6 km	3.1 km
Elkhorn Slough, (Pacific Ocean coastal area North of Monterey Bay, CA)	0.6 km	3.1 km
San Francisco Bay, Southern coastal regions	0.6 km, 0.2 km	3.1 km
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Mono Lake shoreline , East central CA	1.5 km	5 km
Stanislaus Forest, Western Sierra foothills, East central CA	2 km	5 km
Crow's Landing airfield, San Joaquin Valley, CA	2 km	5 km
Salinas Valley, East of Monterey Bay, CA	2 km	5 km
Moss Landing, (Pacific Ocean coastal area North of Monterey Bay, CA)	2 km	5 km
Fort Ord, (Pacific Ocean coastal area North of Monterey Bay, CA)	2 km	5 km
Jasper Ridge, East of Palo Alto, CA	2 km	5 km

wavelength infrared detector array and birefringent interferometer optics [5]. The images acquired were over selected coastal and inland regions of central California. Information about the specific sites that were studied are given in Table 2. Analysis of these images is underway for the study of land and coastal zone conditions and processes. The Mono Lake images are being used to assess the feasibility of a Mars orbiter mission to search for aqueous mineral deposits that may indicate past climate conditions supportive of life.

FUTURE PLANS

Currently, we have several DASI instruments under development that will have improved performance characteristics under a variety of observing objectives. Over the next year, several observation projects are planned. A compact near-IR DASI (0.8 - 2.5 μm) is being designed for use in small aircraft. A DASI using a CCD (Charge Coupled Device) detector array (0.4 - 1.0 μm) is under design for use with a UAV (Unpiloted Air Vehicle) as part of NASA's ERAST (Environmental Research Aircraft and Sensor Technology) program. Spectral images of aircraft contrails and surrounding atmosphere using ground-based DASI sensors are planned as part of NASA's SUCCESS (Subsonic Aircraft:Contrail and Cloud Effects Special Study) field experiment. The contrail studies will be analogous to a previous cirrus cloud study [6]. Development of Algorithms for processing and interpreting interferometric image data is also underway, including the implementation of an unusual noise isolation algorithm [7]. Reference [8] describes other considerations for the development of future DASI type sensors.

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