HYPERSPECTRAL IMAGING CAPABILITIES FOR NATURAL DISASTER ASSESSMENT.

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Introduction: Aerial and satellite hyperspectral imaging is a remote sensing technology that is slowly emerging from the research world and offers the promise of providing detailed information about the condition of the Earth's surface. It is a potentially valuable tool for natural disaster research and assessment and it is worthwhile for the disaster research community to be aware of its capabilities.

Objective: The objective of this paper is to summarize the technology and science of hyperspectral imaging and its application to the monitoring or assessment of natural disasters.

Definition of Hyperspectral Imaging: Hyperspectral imaging is defined as the collection of co-registered electro-optical imagery in hundreds of narrow and contiguous spectral channels. That is, for each pixel in a hyperspectral image a continuous spectrum is available (Figure 1). It is an extension of multispectral imaging (commonly defined as imaging in three to ten, noncontiguous spectral channels) with the hyper prefix implying an "over" sampling of the spectrum.

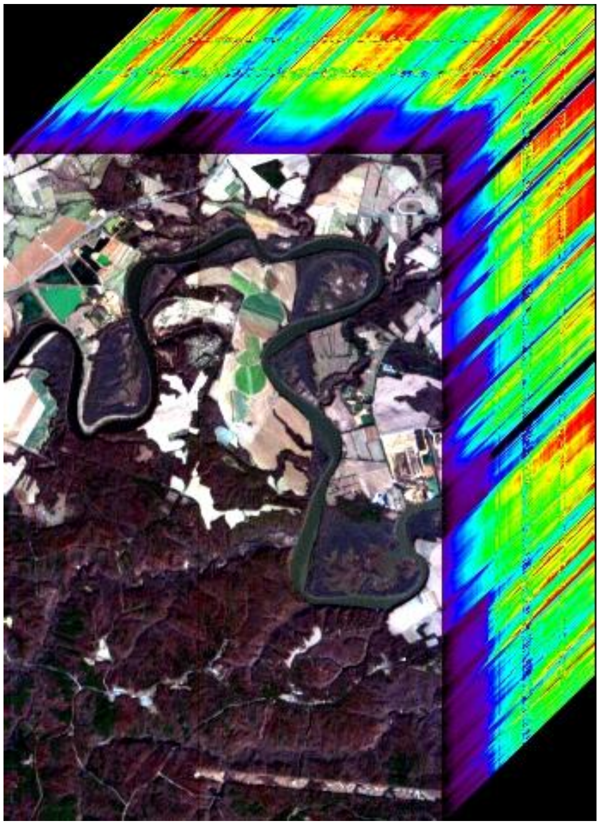

Fig. 1. Hyperspectral image depicted as a cube.

Hyperspectral Imaging Systems: Many hyperspectral imaging systems have been deployed on both satellites and aircraft. However, most are research oriented and under the control of research programs, commercial operators, or military organizations.

Currently, the only spaceborne hyperspectral imager that can be tasked to provide data openly for a small fee is the Hyperion instrument aboard NASA's Earth Observing-1 satellite [1]. Launched in 2000 as a technology demonstration, the satellite has long outlived its planned life and while it continues to provide data, it is running low on fuel and will likely be deorbited within the next few years.

Operated now as an extended mission, Hyperion (and its companion multispectral imager Advanced Land Imager – ALI) is available for tasking and collection of images over customer locations, as well as being operated as part of a Sensor Web [2] demonstration. In this system, the EO-1 satellite is automatically tasked to collect imagery when queued by other satellite sensors or ground based systems detecting a natural event such as a forest fire or volcano eruption.

However, due to orbital and field of view limitations inherent in satellite sensors, it may be several days before a satellite can be in range of collecting data over a disaster event. Also due to the high orbital altitude and limited aperture size, satellite instruments are limited in spatial resolution. For example, Hyperion pixels have a ground size of 30 meters.

Airborne hyperspectral imagers can provide data more quickly and at higher spatial resolutions. While a modest number of commercial vendors offer collection services for a fee, the U.S. Civil Air Patrol (CAP) is acquiring up to sixteen hyperspectral imaging systems to equip their fleet of emergency response aircraft. The ARCHER system [3] is being deployed specifically to assist with search and rescue (SAR) missions and to respond to emergencies, both man-made and natural. As one example of how these systems have been used, CAP planes equipped with the ARCHER system were used in the recent unsuccessful search for missing adventurer Steve Fossett in the western US. More examples are described below.

While primarily a research instrument, the airborne AVIRIS sensor [4] operated by NASA's Jet Propulsion Laboratory has been used in disaster mapping situations. Within days of the September 11, 2001 attack on the World Trade Center, AVIRIS collected images of the site with a goal of mapping the fallout of hazardous asbestos released during the building collapse [5].

Data Analysis Techniques: The physical quantity measured by a hyperspectral imager (assuming calibration) is *spectral radiance* (Watts-m^{-2}-ster^{-1}-µm^{-1}). This quantity represents the solar reflected (or thermally emitted) energy from the surface after passing through the intervening atmosphere. The inherent parameter that contains the information about surface materials or their condition is *spectral reflectance*. Most hyperspectral image analysis techniques start by compensating the spectral radiance for the effects of solar illumination and the atmosphere to convert the data into spectral reflectance.

Figure 2 shows example results from this atmospheric compensation process applied to Hyperion data. As can be seen, there are gross differences across the spectrum between the three materials suggesting these materials are easily differentiated. A few features deserve some explanation. Note the "holes" in the data around 1400 and 1900 nm. Atmospheric water vapor strongly absorbs in these regions and no radiance reaches the instrument. It can be seen that little radiance is reflected from water surfaces at wavelengths beyond 1000 nm making the data at those wavelengths useless for monitoring water characteristics. Also, the green peak (~500 nm) and high near infrared (700 – 1000 nm) reflectance of vegetation allow it to clearly stand out from water or soil.

Narrow spectral features can indicate the presence of particular minerals [6], although for the data shown in Fig. 2, many of the fine features are most likely due to measurement noise in the instrument. Changes in the slope of the vegetation "red-edge" (~700 nm) can be indicative of plant stress due to low moisture or disease. Processing of these data is most commonly done by a trained analyst [7], although some progress has been made in automated methods [8].

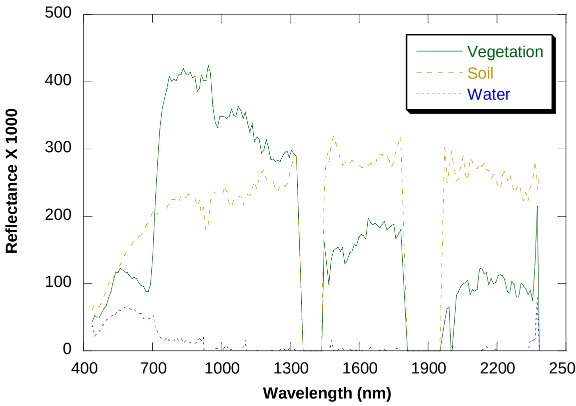

Fig. 2. Single pixel spectral reflectances derived from Hyperion imagery for sample surface types.

Application to Disaster Response: Hyperspectral imaging has been applied to many natural (and man-made) disaster situations. A brief sampling follows.

Volcanoes. The Hyperion instrument aboard EO-1 has been autonomously tasked to image volcanoes based on eruption detections made by ground-based or other remote sensing satellite sensors [9]. These data have been used to obtain a thermal summary of the area as well mapping of the ash cloud and sulfur dioxide plume. Airborne hyperspectral imagery has been used to obtain detailed structural, petrological, and biological maps of volcanoes [10].

Hail Storms. A study by researchers from Australia [11] looked at the use of airborne hyperspectral imagery to map roof material types. These maps were then combined with other Geographic Information System (GIS) information in a spatial decision support system to assist in post damage emergency operations.

Agricultural Disease and Stress. Hyperspectral imaging can detect and map stress due to water shortage, disease, or insect infestation in agricultural crops before such stress is visible to the eye. One example is the mapping of salt-damaged rice paddy fields [12]. In this case salinized winds caused damage to the fields and their experiments showed hyperspectral imagery can detect this stress at an early withering-up stage.

Unnatural Disasters. In addition to the mapping of the fallout from the World Trade Center collapse mention earlier, airborne hyperspectral imagery has been applied to the characterization of environmental contamination. A joint project between the University of Missouri and the Environmental Protection Agency used the CAP ARCHER system to map contaminants from an industrial gas fire [13].

Summary: While neither routinely nor easily available, hyperspectral imagery offers significant capability to aid in responding to natural disasters.

References: [1] Pearlman, J. et al. (2000) *Proc. SPIE Vol. 4135*, 243-253. [2] Mandl, D. et al. (2005) AMS Annual Mtg. [3] Stevenson, B. et al. (2005) *Proc. SPIE Vol. 5787*, 17-28. [4] Green, R. et al. (1998) *Rem. Sens. Env*. 65, 227-248. [5] Clark, R. et al (2001) USGS Report OFR 01-0429. [6] Clark, R. et al (2003) JGR 108(E12), 5131. [7] ENVI, www.ittvis.com/envi/. [8] Stevenson, B. et al. (2005), *Proc. SPIE Vol. 5806*, 731-742. [9] Davies, A. et al. (2006) *Eos* 87(1), 1 & 5. [10] Martini, B. A., Silver, E. A., and Pickles, W. L. (2000) *AGU Fall Meeting*, paper V22F-05. [11] Bhaskaran, S. et al. (2001) *22nd Asian Conf. Rem. Sens.*, Nat. Uni. Singapore. [12] Minekawa, Y. et al. (2005) *Proc. of IGARSS'05*, 2153-2156. [13] Carbone, N. et al. (2005) Missouri Dept. Nat. Res., *Contam. Character. through Airborne Hyperspectral Imagery Pilot Project Fin. Rep*.