Satellite sends hyperspectral images from space

05/01/2001

J. Bruce Rafert, Leonard. J. Otten, Eugene. W. Butler, and Andrew D. Meigs

Extremely stable solid-block Fourier interferometer design minimizes risk of imager misalignment or damage amid shocks and rigors of launch and low-Earth orbit.

On Aug. 1, 2000, within days of a picture-perfect launch on July 19, the Fourier Transform Hyperspectral sensor aboard the US Air Force MightySat II.1 sent back its first "hypercube" from orbit, ushering in a new era in remote sensing from space. A modified Air Force Minuteman missile provided a smooth ride to a 575 km 97.3° inclination low-Earth orbit carrying a variety of scientific experiments aboard MightySat II.1—including the world's first functioning hyperspectral imager (see Fig. 1, left).

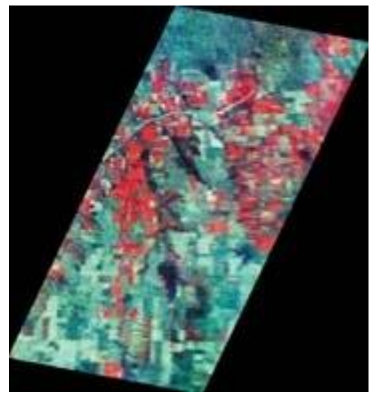


FIGURE 1. Mighty Sat II.1 satellite in low-earth orbit (below) last year provided the first hyperspectral images from orbit of a Colorado landscape (right). Red areas on landscape near Keenesburg correspond to healthy vegetation, while Interstate 76 cuts diagon-ally across the upper left of the image and Horse Creek reservoir (lakes show as blue in this image) and dam are shown in the lower right. North is up. (Photo courtesy of US Air Force Research Lab)

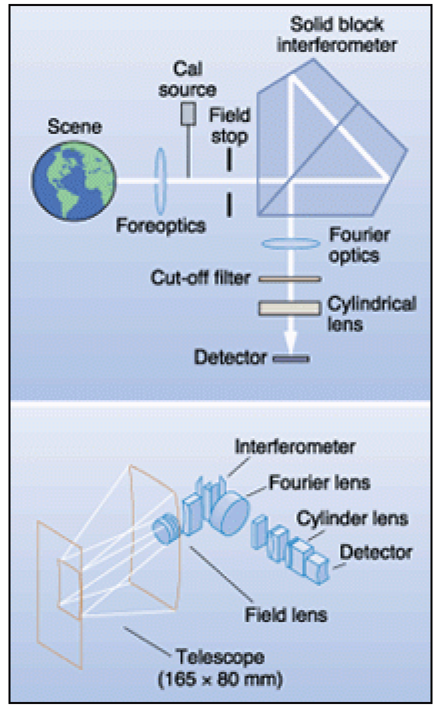
The hypercube data structure received from the hyperspectral sensor consists of both two-dimensional image (spatial) and spectral data expressed in a Cartesian cube, where the *x*-*y* plane provides the image and the *z* axis provides the spectrum.

A false-color RGB rendering of this first image displays a scene near Keenesburg, CO (see Fig. 1, right). Just three of the 145 narrow-band 87 cm^{-1}-wide channels are utilized to construct an RGB image using the 775-, 651-, and 551-nm bands respectively. Spatial resolution is approximately 30 m, and the image is 15 km wide by 27 km long, about half the maximum size that can be collected. With an equatorial crossing at 1115 Universal Coordinated Time (UTC)—right before local noon ensuring optimal sun illumination angle—MightySat II.1 is positioned to observe a variety of important environmental, industrial, commercial, and military targets.

Principles of operation

The MightySat II.1 hyperspectral imager utilizes an imaging solid block Fourier Transform interferometer (see Fig. 2). Light from Earth is focused to an intermediate image plane by a set of foreoptics, where a spatial mask may be inserted. Each ray from the target is split at the beamsplitter interface (the diagonal line in the figure), following the classic Sagnac or "triangle path" configuration. The two mirrors are just aluminized surfaces of the interferometer itself. A Fourier optic ensures that the resulting interferogram is displayed on the charge-coupled device (CCD), while the cylindrical lens reimages one dimension to supply a spatial dimension on the detector. Hence, the CCD receives an interferogram in the horizontal direction that contains spectral information for each pixel that is imaged in the vertical, or spatial dimension, allowing the sensor to operate as a pushbroom imager.

FIGURE 2. The solid block interferometer design enables the device to withstand shocks and stresses of launch and orbital operation (top). Matching geometry between foreoptics and detector allow for different horizontal and vertical system magnifications (center). The assembled system (bottom) includes the entire cylindrical optics subassembly, side bonded following laboratory spacing, alignment and calibration, and ready for integration. (Photo courtesy of US Air Force Research Lab)



The interferometer is an innovative solid block design that supplies an optimal path offset via a design that is extremely stable and immune to damage or misalignment during launch and on-orbit operations.[1] It is also worth noting that the *f/#* in the spatial dimension is 3.4, while the spectral dimension works at *f*/5.3. These two design features, coupled with the other well-known advantages of a Fourier transform instrument, give MightySat II.1 exceptional performance capabilities. Square foreoptics (165 x 80 mm) match the geometry of the detector, allowing for different horizontal and vertical system magnifications, and ensuring sensibly equal aperture functions and self-apodization for each horizontal row of the CCD. The optical components in the system are also bonded into "monolithic" packages to render them resistant to misalignments and thermal distortions.

Project heritage

The Fourier transform instrument that is flying on MightySat II.1 has a design heritage spanning more than a decade. A distant relative of this instrument—the Malabar Hyperspectral Imager—obtained the first spectral signatures of satellites in space seen from the ground, including the first hypercube of the space station Mir. A long series of Small Business Innovative Research (SBIR) grants and internal research and development initiatives led by Kestrel Corporation and Michigan Tech helped place the requisite science and technology on a fully operational footing, first via development of the Kestrel Fourier Transform Visible Hyperspectral Imager (FTVHSI) airborne sensor, and then MightySat II.1 itself.[2, 3] Significant milestones included design and construction of the optical system, as well as the associated onboard data logging and preprocessing algorithms.

FIGURE 3. Following final system and integration tests, the hyperspectral imager will sit on the top of the satellite covered with reflective mylar with the open input aperture open to the left. The articulating solar wings are not yet installed, and the cables are supplying ground power.

The MightySat II.1 satellite was constructed as part of an ongoing US Air Force Research Laboratory (AFRL) space test program designed to provide space heritage to new high-risk high-payoff space technologies (see

Fig. 3). The spacecraft also carries several materials science experiments and experimental space components in addition to the hyperspectral imager.

The satellite and its imager are being operated by a small team of in-house AFRL engineers located at Kirtland Air Force Base (Albuquerque, NM). Between three and four images are collected and downloaded each week from a variety of targets (see Fig. 4). To date the Air Force has collected more than 80 images covering more than 25,000 Km^2 data from the hyperspectral imager. Plans to make selected sets of the imagery available to interested users are being implemented by way of a Cooperative Research and Development Agreement (CRADA) between AFRL and Kestrel. With the finalization of this CRADA, scheduled for mid-March, many of the images in the Air Force archives will be available onKestrel's web site, www.kestrelcorp.com.

FIGURE 4. Might Sat II.1 has provided the first hyperspectral images of Earth's limb. (Photo courtesy of US Air Force Research Lab)

The group's design efforts continue to probe the frontiers of imaging spectroscopy and hyperspectral imaging, with projects involving long-wave infrared ultraspectral imagers, computed tomography hyperspectral imagers, medical applications of hyperspectral imagery, and infrared and ultraviolet hyperspectral sensors.

ACKNOWLEDGMENTS

The authors gratefully acknowledge support for this project by the US Air Force Research Laboratory Space Vehicles Directorate at the Kirtland Air Force Base in Albuquerque, NM.

REFERENCES

1. Rafert, J.B., Sellar, R.G., Blatt, J.H., Applied Optics 34 (31) 7228 (1995).
2. L. J. Otten, E. W. Butler, J. B. Rafert, R. G. Sellar, Aerosense '95, Orlando, FL.
3. L. J. Otten., A. D. Meigs, R. G. Sellar, J. B. Rafert, SPIE Proc. of the Int. Symp. on Opt. Sci., Eng., and Instrum. (Denver), 2819, 291(1996).

J. BRUCE RAFERT chairs the Department of Physics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931; e-mail: jbrafert@mtu.edu. Eugene W. Butler is president and Leonard J. Otten is vice president of Kestrel Corp., 3815 Osuna NE, Albuquerque, NM 87109; e-mail: www.kestrelcorp.com. Andrew D. Meigs is a research scientist at Rio Grande Medical Technologies, 800 Bradbury SE, Albuquerque, NM 87106 email: andrewmeigs@rgmt.com.