National Aeronautics and Space Administration

Real-Time Reconfigurable Full-Frame/Hyperspectral Imager

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Program: R&TD Topic Area

Project Objective:

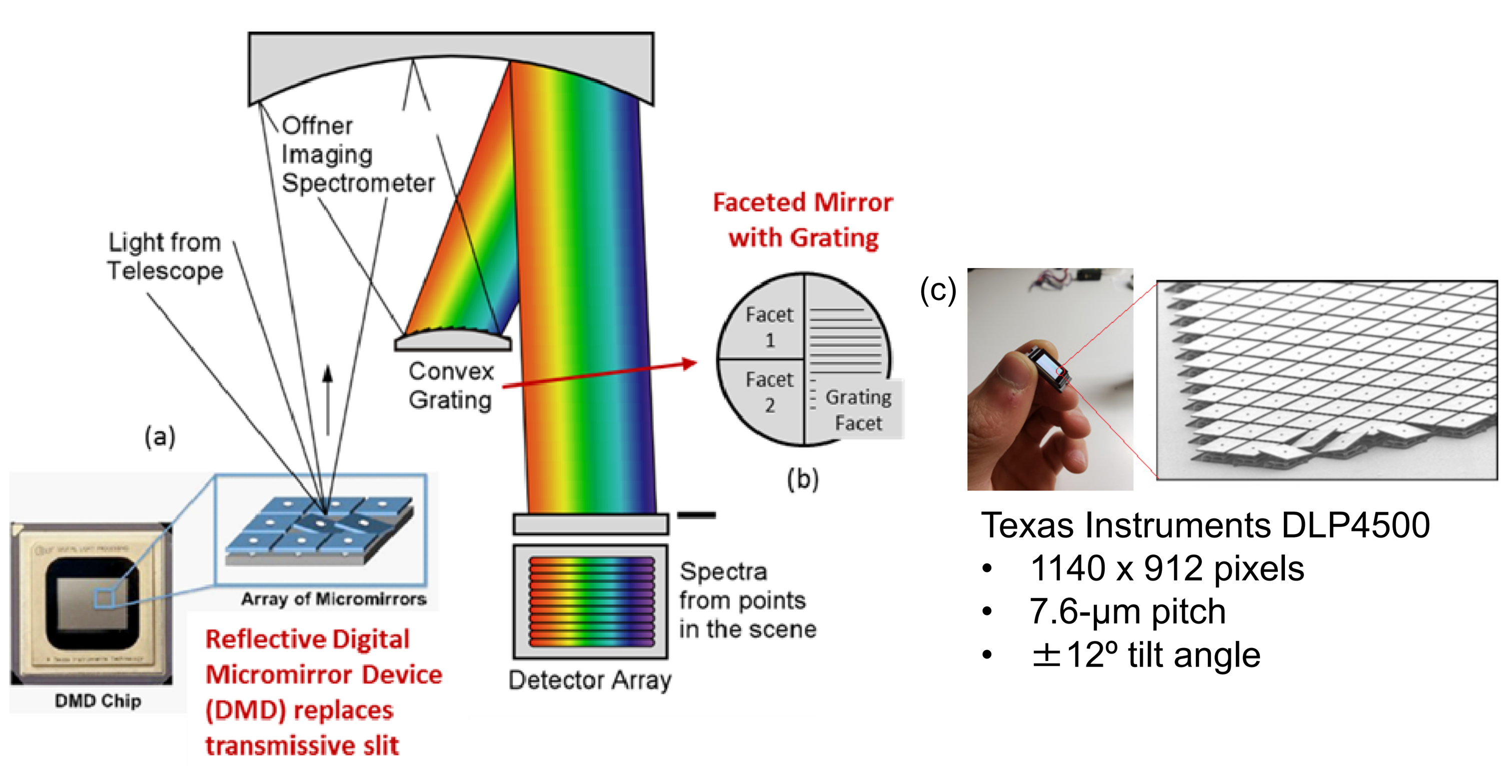
Our objective is to develop a system capable of switching between full-frame imaging and hyperspectral imaging of selected points within a scene. This capability will be enabled by combining JPL's techniques for electron-beam fabrication of diffraction gratings for Offner spectrometers with a programmable digital micromirror device (DMD) to select points of interest within the scene.

FY18/19 Results:

1. **System design**: We have performed optical design (sequential and non-sequential ray tracing) of an Offner spectrometer including a multi-mirror DMD model at the input (Fig 1a). We investigated effects of DMD tilted-image-plane compensation and primary lens designs (f-number, telecentricity).
2. **Grating design and fabrication**: The grating was designed so that both the 0th and 1st orders fall on the focal plane array. The 0th order is undispersed for imaging and the 1st order is dispersed and hence can be used for the pixel spectra retrieval.
3. **Compact system development**: Completed assembly and alignment of a new, compact spectrometer design (Fig 2). In doing so, we reduced the size (six-fold) and weight (ten-fold) of the previous benchtop setup by procuring and interfacing a new DMD. The new design is transportable for measurements of outdoor targets.
4. **Indoor calibration and outdoor testing**: Began measurement and instrument calibration using calibrated spatial and spectral targets (Fig 4-6). Demonstrated the system's ability to resolve spectral lines in rare-earth materials.

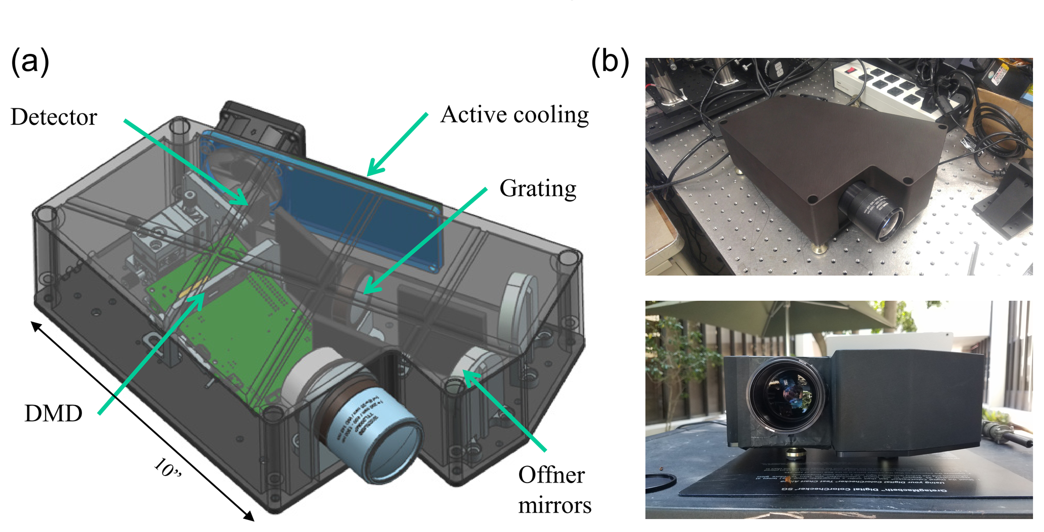
Benefits to NASA and JPL (or significance of results):

Recent years have seen the development of a variety of new small science gathering platforms: airborne drones, unmanned aerial vehicles, spaceborne cubesats, and smallsats. While they have the potential to host traditional imaging and spectroscopic instruments, they are often not as stable or flexible as aircraft or spacecraft. To address these issues, and to open up many new science opportunities, we are developing an optical system that has the ability to perform real-time switching between full-frame (or multi-band) and hyperspectral imaging of regions of interest. Such a system could be programmed to first perform full-frame panchromatic or multi-band imaging, and then retrieve the full detailed spectra of pixels that have certain spatial shapes, brightness relative to background, or multi-band spectral ratios. This operation could be remotely guided or autonomous and would reduce data volume, hence providing more unique spectra per imaging opportunity compared to scanning slit imaging spectrometers. Furthermore, this three-instruments-in-one package would have reduced size, weight, and power compared to multiple instruments. The progress to date will enable us to optimize and demonstrate our reconfigurable spectrometer testbed in the coming year. With successful demonstration of reconfigurable imaging and spectroscopy of synthetic and laboratory scenes, JPL will be in a strong position to propose to future opportunities for earth and planetary instrument development.



Texas Instruments DLP4500
- 1140 x 912 pixels
- 7.6-µm pitch
- ±12º tilt angle

Figure 1. (a) Reconfigurable full-frame/hyperspectral imager optical system illustration. Programmable DMD pattern can be changed at kHz rates to selectively reflect scene pixels/regions-of-interest into the spectrometer for for hyperspectral analysis. (b) Example of forthcoming faceted secondary mirror layout with two mirror facets and a grating. (c) Views and specifications of micromirror array.



(c)

1st Order System Properties	
F-number	F/20
FOV	~2.9°
Focal length	400mm - ∞
Spectral range	460 – 720 nm
Spectral sampling	0.53 nm
Volume	5.5 U (5,500 cm³)
Detector pixels	4112 x 3008
High-res imaging time	10 min
High-speed imaging time	20 s

Figure 2. (a) CAD screenshot showing primary DMD spectrometer components. (b) Photos of as-built system during laboratory and outdoor testing. (c) Table of first-order system properties. Future work will improve the system F-number for faster image collection.

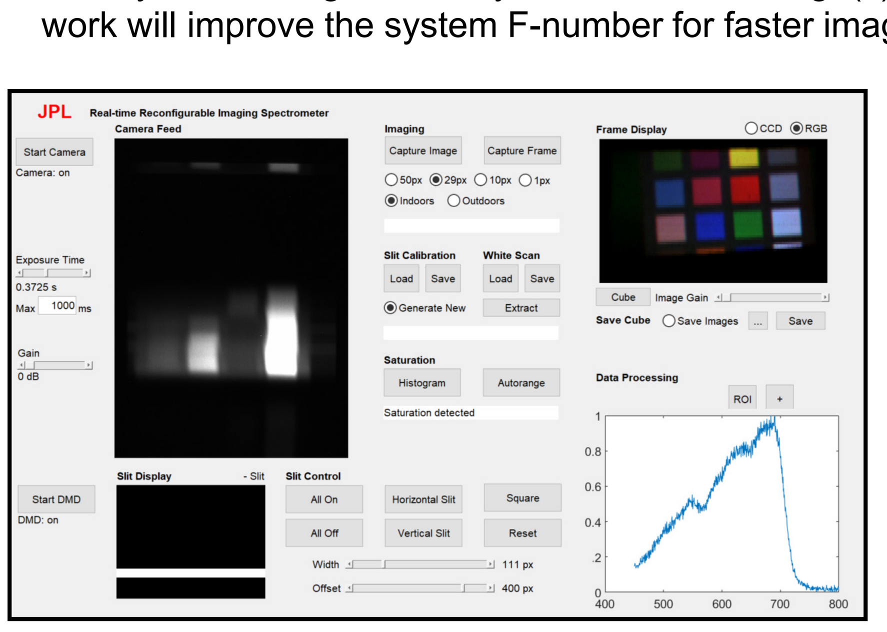


Figure 3. Custom MATLAB graphical user interface (GUI) allows real-time operation in full-frame and spectral modes, recording and applying calibration files, and tuning of system parameters.

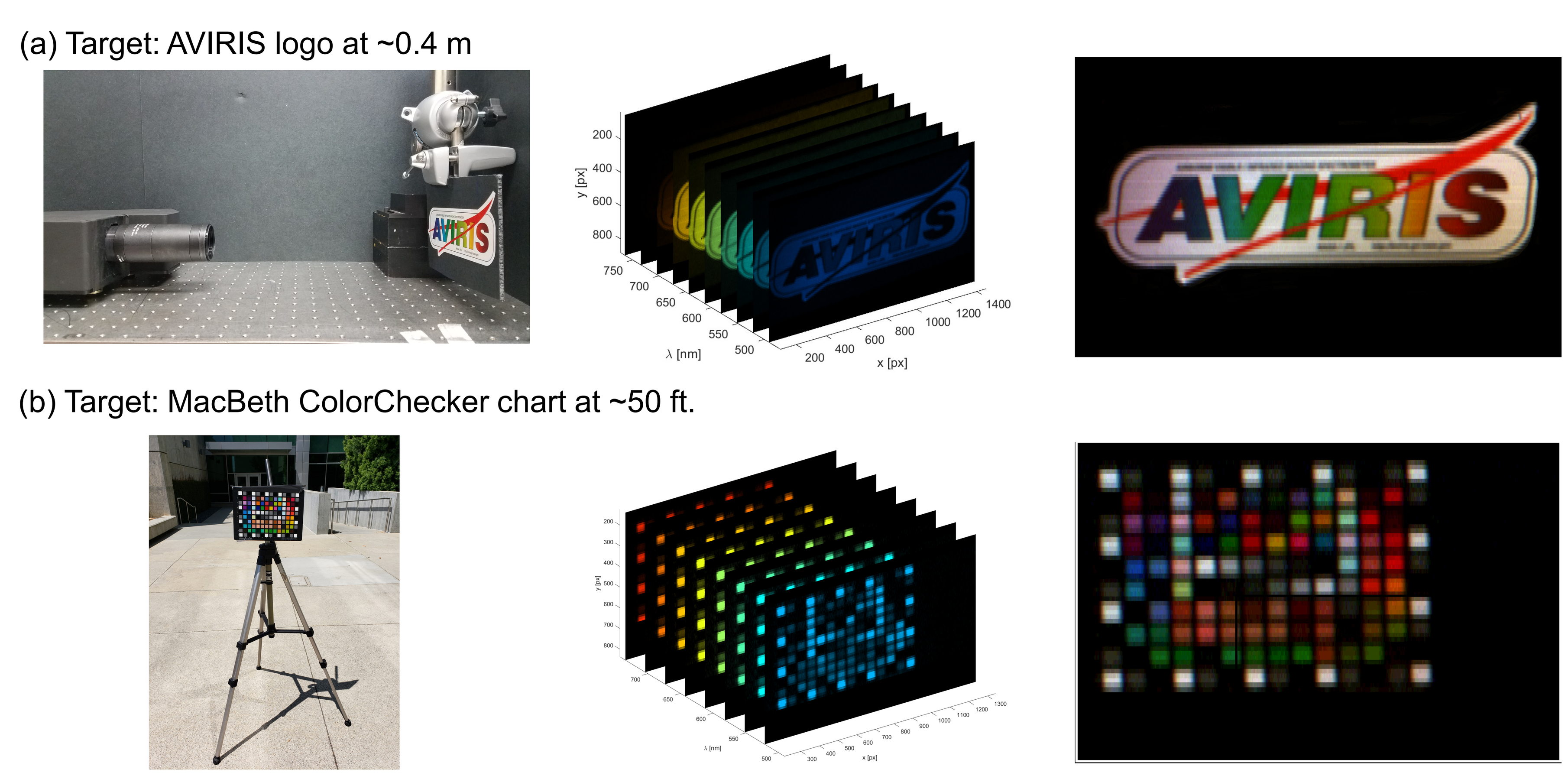


Figure 4. (a) Laboratory imaging of a close-proximity target, 3-D image cube, and color image reconstructed from RGB channels. (b) Outdoor imaging of a distant target, 3-D image cube, and color image reconstructed from RGB channels.

(a) 50 px slit, ~20 sec measurement (b) 29 px slit, ~1 min measurement (c) 10 px slit, ~9 min. measurement

Figure 5. (a) High-speed imaging mode uses a broadened slit, sacrificing spatial and spectral resolution for imaging time. (b) A mid-sized slit offers a good balance between resolution and imaging time. (c) A narrow slit provides high-resolution imaging but is susceptible to changes in scene and lighting conditions.

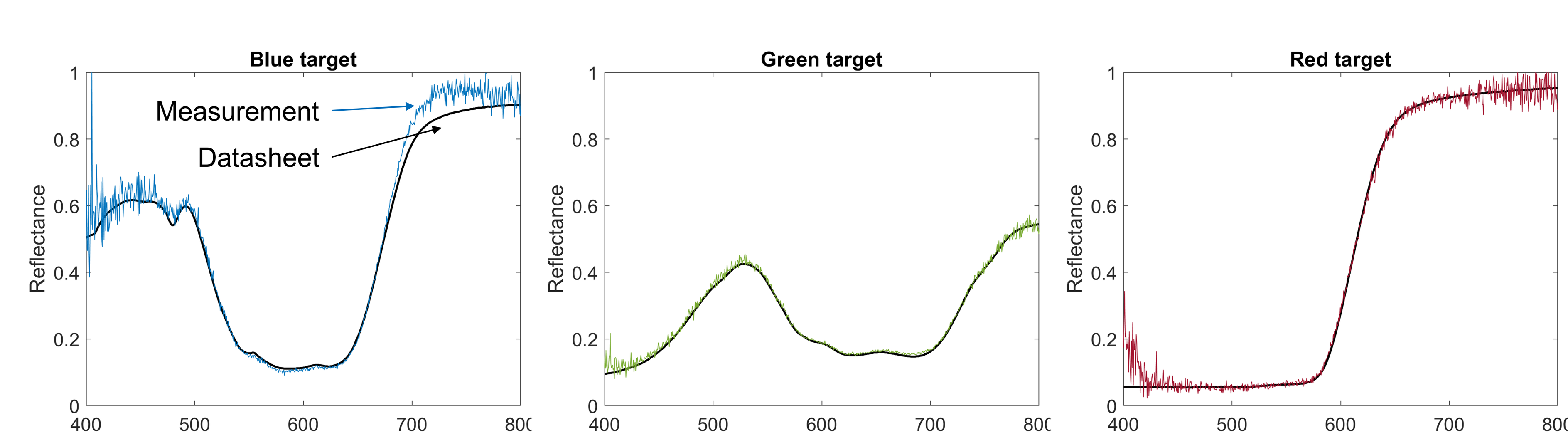


Figure 6. Laboratory reflectance testing using calibrated Labsphere color targets. Reflectance was calculated after measuring the system response using a white Spectralon sample.

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