National Aeronautics and Space Administration

# Real-Time Reconfigurable Full-Frame/Hyperspectral Imager


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**Program: FY21 R&TD Topics** **Strategic Focus Area: Remote/In Situ/Life Detection Sensors and Instruments**

## Objectives

Our goal is to develop a compact instrument 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 rapidly select and reconfigure points of interest.

## Background

Recent years have seen the development of a variety of new small science gathering platforms: airborne drones and unmanned aerial vehicles, and 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 traditional aircraft or spacecraft. To address these issues, and to open up many new science opportunities, we aim to develop a compact optical instrument that has the ability to perform realtime switching between full-frame (or multi-band) and hyperspectral imaging of regions of interest. Such a rapidly-reconfigurable and two-in-one system would enable new opportunities for in-situ and remote sensing of visible and short-wave infrared (VSWIR) sources, including vegetation productivity, mineral composition, and anthropogenic activity such as pollution or wildfires.

## Approach and Results

JPL has been electron-beam fabricating high-performance blazed gratings on convex substrates for Offner spectrometers for many years. In this work, to enable reconfigurability, the Offner entrance slit is replaced by a reflective Texas Instruments Digital Micromirror Device (DMD) that is an array of micromirrors (up to 1140x912) that reflects light from desired pixels in the input image (from lens/telescope) into the Offner spectrometer (Fig. 1). The DMD can switch its mirror array configuration at kHz rates, and hence it can switch in real time from reflecting a full frame of pixels into the Offer to a single pixel, multiple pixels, or a slit of pixels. In full-frame mode, each mirror facet without a grating forms a full-frame image on the detector that can be unfiltered (panchromatic) or filtered (multi-band). Real-time analysis of the full-frame images can be used to select pixels of interest. The DMD can then turn 'on' (reflect) only those pixels, and their spectra can be detected in the dispersed image resulting from the grating. We have made excellent progress toward demonstrating this type of imaging spectrometer. The specific accomplishments of this development effort are as follows:

1. We utilized Zemax optical design software to perform sequential and non-sequential ray tracing of an Offner spectrometer including a multi-mirror DMD model at the input. We investigated effects of DMD tilted-image-plane compensation and primary lens designs (e.g., f-number and telecentricity).

2. We used grayscale e-beam lithography to fabricate a convex grating on a spherical mirror substrate, using the $0^{th}$ and $1^{st}$ orders to form the undispersed and dispersed images. We have procured a faceted mirror substrate and started grating fabrication.

3. We completed assembly and testing of a compact visible system capable of capturing spectra from selected pixels within a scene (Fig. 2). The system is transportable and completed measurements of both indoor and outdoor targets.

4. We programmed a custom MATLAB graphical user interface (GUI) (Fig. 2) that allows for real-time operation of the instrument in both fullframe and hyperspectral modes.

5. We performed laboratory measurement and instrument calibration using calibrated spatial and spectral targets, and outdoor measurements of resolution targets and natural sources (Figs. 3). We demonstrated the system's ability to resolve spectral features in calibrated color targets (Fig. 4) and rare-earth materials.

6. We designed an all-reflective system to operate in near infrared wavelengths (1.0-1.7um) (Fig. 5). The system utilizes custom optics to improve the system F-number, field-of-view, and spectral range. A faceted grating will be fabricated for separating the undiffracted (panchromatic) and diffracted (spectral) signals on the detector. All the custom optics have been received, including the faceted grating substrate. The grating can be fabricated and the system assembled into a working NIR system if follow-on funding is identified.

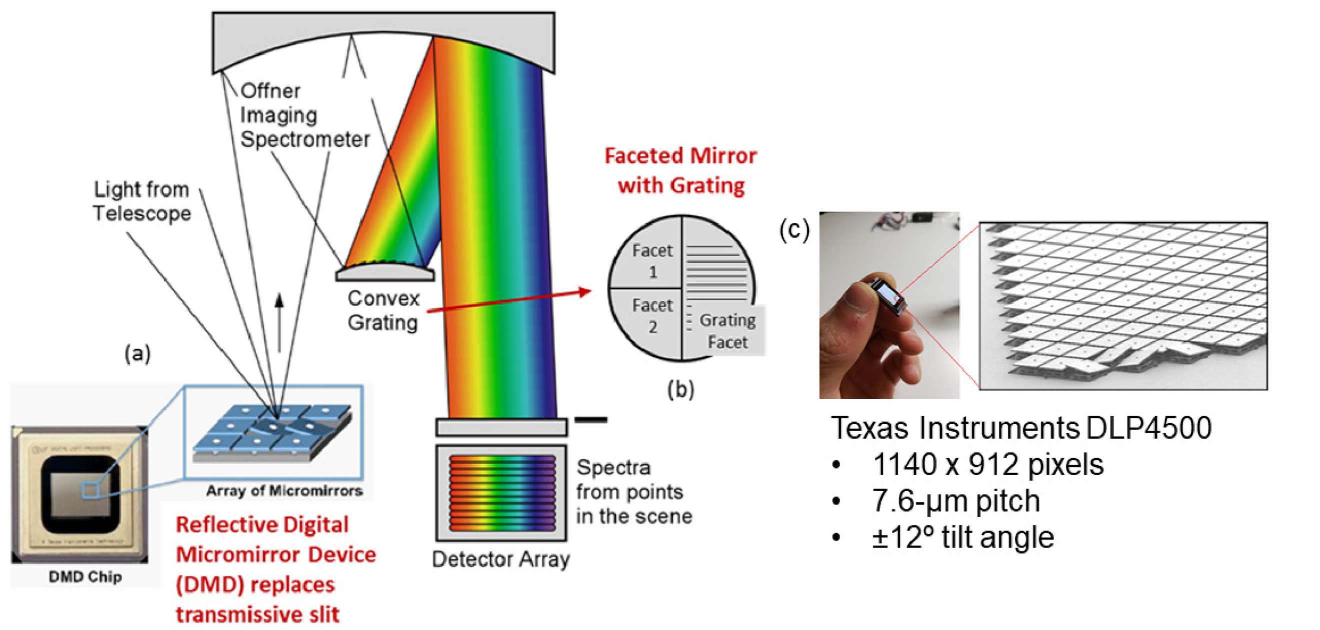


**Figure 1**. (a) Reconfigurable full-frame/hyperspectral imager optical system illustration. (b) Example of faceted secondary mirror layout with two mirror facets and a grating. (c) Views and specifications of micromirror array.

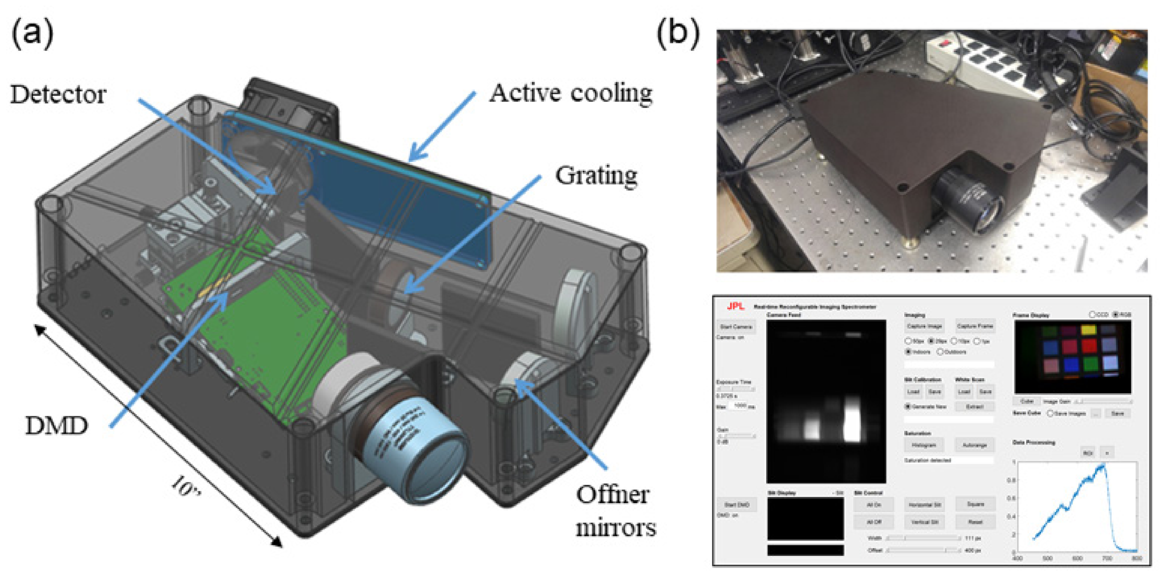


**Figure 2**. (a) Design showing primary DMD spectrometer components. (b) Photos of as-built system during and custom MATLAB graphical user interface for real-time operation and calibration.

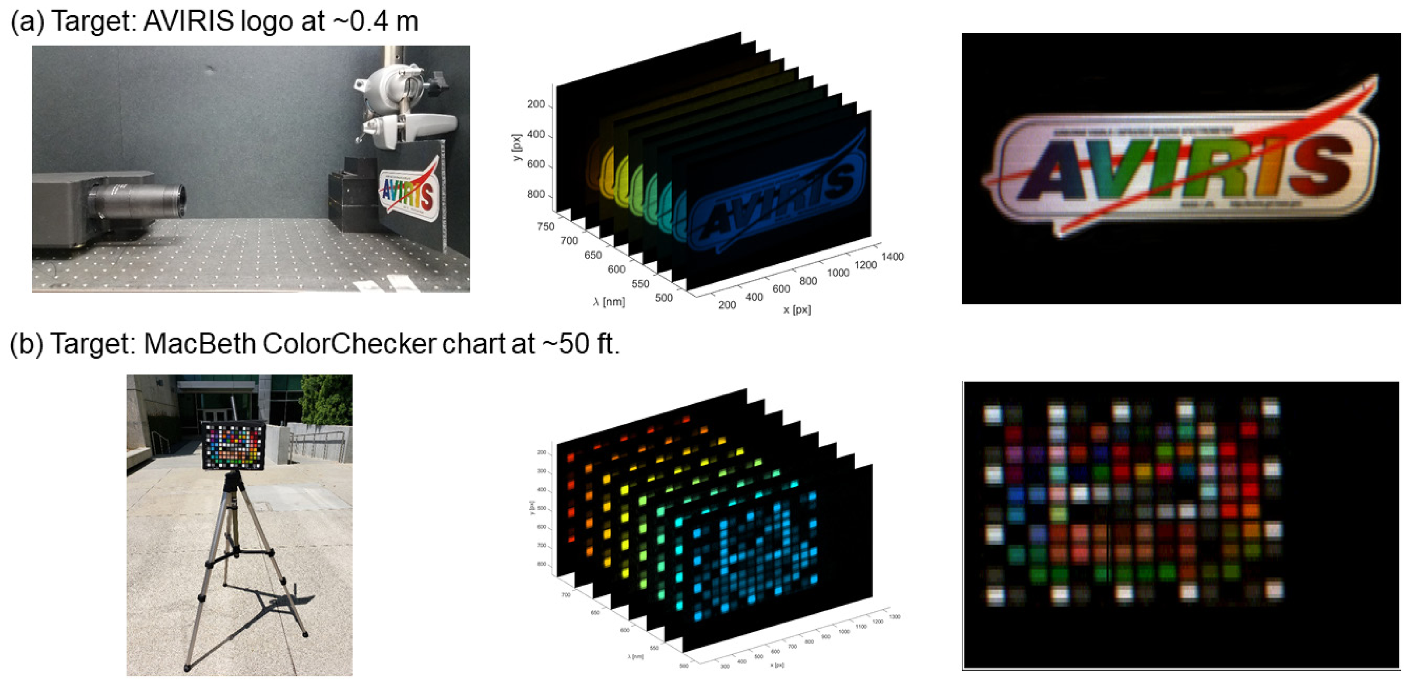


**Figure 3**. (a) Laboratory imaging of a close-proximity target, 3-D image cube, and color image reconstructed from RGB channels. (b) Outdoor imaging of a distant target, 3-D image cube, and color image reconstructed from RGB channels.

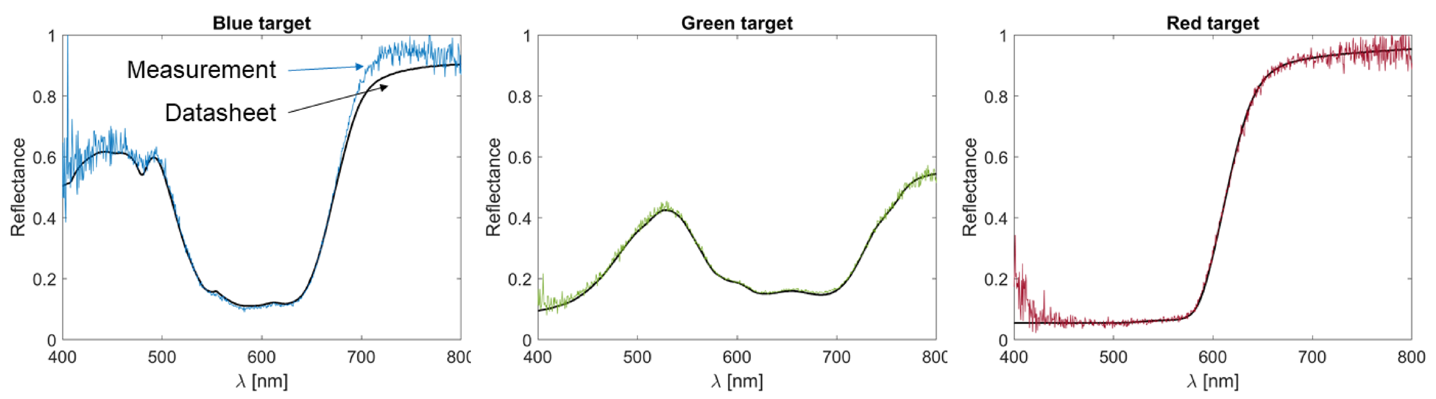


**Figure 4**. Laboratory reflectance testing using calibrated Labsphere color targets.

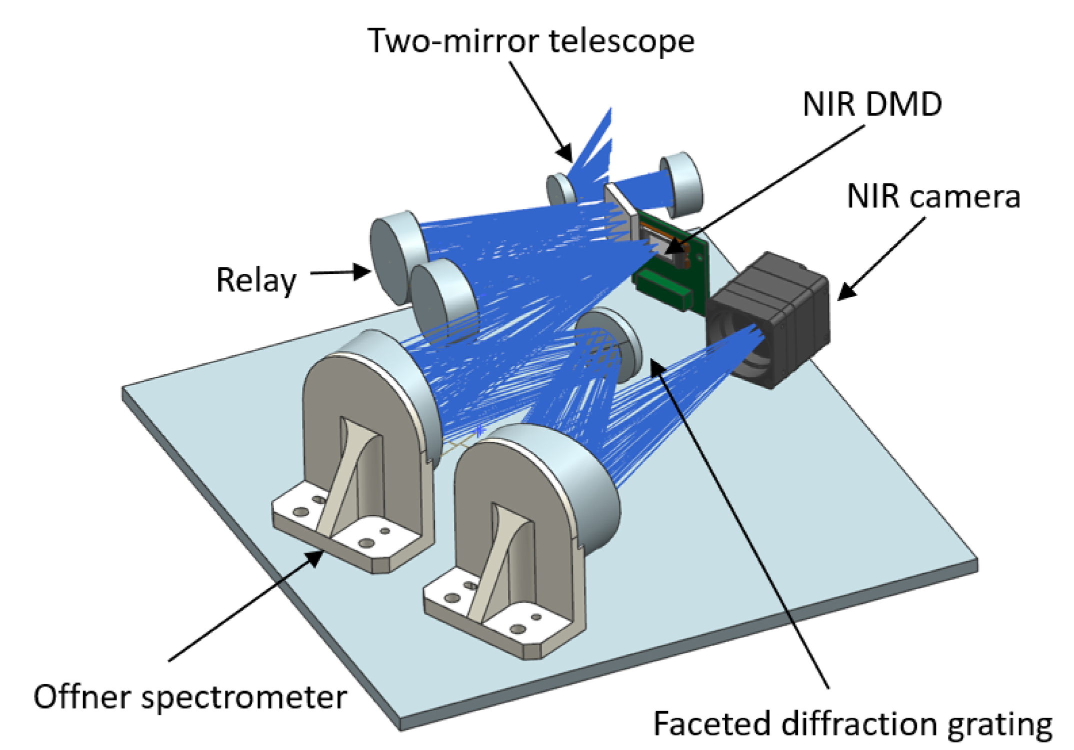


**Figure 5**. All-reflective system designed to operate in NIR (1.0-1.7um) wavelengths utilizing custom optics and faceted grating. All parts have been procured.

## Significance/Benefits to JPL and NASA

We have demonstrated compact, functional, visible (near infrared designed/parts-procured) DMD spectrometer systems capable of switching between full-frame and hyperspectral imaging of regions of interest. The systems can 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 two-instruments-in-one package could have reduced size, weight, and power compared to multiple instruments. The systems will have the potential to integrate with a variety of new small science gathering platforms: airborne drones and unmanned aerial vehicles, and spaceborne cubesats and smallsats.


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