Design and Fabrication of a UV-Visible Coded Aperture Spectral Imager (CASI)

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Abstract: CASI is a snapshot capable UV-visible spectral imager for measuring bird plumage. Near apochromatic UV-visible optics were designed and built with an MTF for a 4Mpx detector. Wide-spectral bandwidth data from CASI is then presented.

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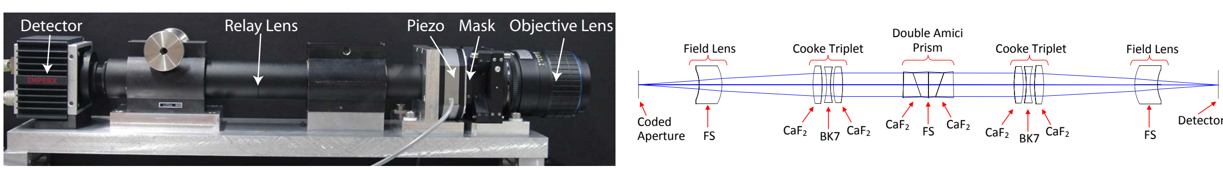
1. Introduction

Coded aperture snapshot spectral imagers (CASSI) [1] estimate a three-dimensional spatio-spectral data cube from a single two-dimensional coded projection on a detector. The number of pixels on the detector match a single slice of the data cube. The raw data from the detector is a compressive measurement in the spectral dimension by the number of spectral channels, which gives a highly underdetermined system operator. Reconstruction of the data cube is preformed by two-step iterative shrinkage/thresholding (TwIST) [2, 3]. To better estimate the data cube additional information can be gained by scanning the aperture code for each new frame [1]. Each frame is still a valid snapshot that can be reconstructed for an estimate, while many frames can be reconstructed together for high resolution.

Currently, only limited spatial and spectral resolution has been achieved for this type of instrument using off-the-shelf optics. By completely redesigning the optics of the system using custom lenses and mechanics, a new instrument has been built that far exceeds the spectral range and MTF specifications of previous instruments. The UV-CASI instrument is being used to study avian bird plumage at Yale University, specifically requiring UV spectral data. Birds are tetrachromats, meaning they have four separate color receptors, one specifically for UV. Furthermore, the spatial features of bird feathers are very fine, requiring high resolution.



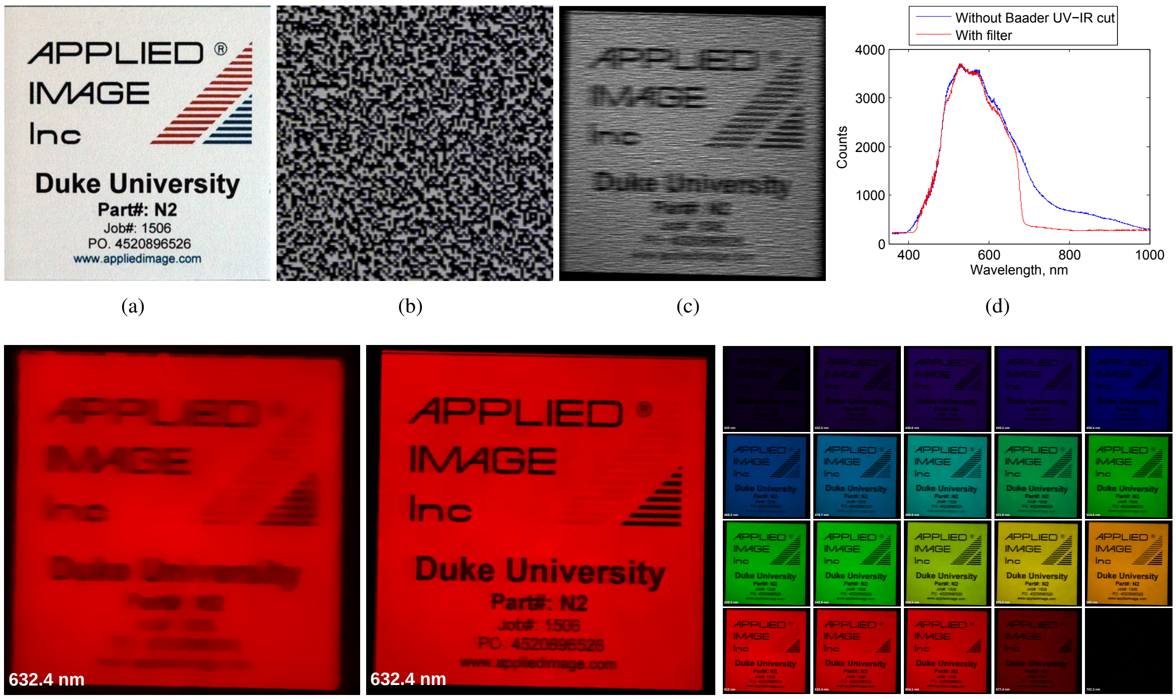
(a) (b)

Fig. 1. (a) Coded aperture spectral imager; (b) custom relay lens design.

2. CASI System

A new hyperspectral imager shown in figure 1(a) has been developed to meet these requirements with a spectral range of 300-700nm and nearly 100 channels. The optics have also been completely custom designed for this specific application, greatly enhancing the performance of the instrument compared to the previous generation system [1]. The camera is an Imperx Lynx IPX-4M15 UV-enhanced 2048x2048 monochrome detector. The aperture code is a random pattern lithographically etched on a quartz substrate by Photo Sciences with an active area of 14.7112mm square. The aperture code is imaged onto the detector $1:1$ by the relay lens (custom fabrication by Shanghai Optics) and dispersed by a double amici prism. The aperture code is modulated by a piezo system (Newport Corporation) by up to 21 pixels on the detector. The objective lens was provided by Coastal Optics and is a true apochromat across the entire spectral range of the instrument.

At the heart of the system is a newly designed relay lens in figure 1(b) consisting of a modified Cooke triplet with field lenses. The system is symmetric around the prism, which is in the collimated space of the Cooke triplet. The 7.4μm pixels of the detector require an MTF of at least 67.6$\ell p/mm$, while the aperture code (shown in figure 2(b)) size specifies the FOV. The entire spectral range of $300-700nm$ must be focused at all wavelengths, ideally being apochromatic. The difficulty with this wavelength range is that most glass types do not transmit below 350nm. Fused silica (FS), calcium fluoride (CaF_2), and magnesium fluoride (MgF_2) transmit well below 300nm, but because of MgF_2 being birefringent, it is not preferred by Shanghai Optics. With only two glass types, color correction is nearly impossible, so BK7 was considered, which for 5mm thickness transmits close to 90% above 320nm. Compromising slightly at the lower UV significantly improved the MTF, with a minimum of $40-80\ell p/mm$ and most areas and wavelengths above $90\ell p/mm$.



(a) (b) (c) (d)

(e) (f) (g)

Fig. 2. (a) RGB image of object; (b) small section of aperture code at detector for monochromatic illumination; (c) raw data at the detector through UV-CASSI of scene; (d) white light spectra from Ocean Optics; (e) 632nm Snapshot reconstruction; (f) 632nm 24-pushbroom-frame reconstruction; (g) Selected wavelengths from full spectral datacube.

3. Data

The example data set was acquired by illuminating the object shown in figure 2(a) with wide spectra sunlight emulation Solux lamps. A Baader UV-IR cut filter was used to omit the IR spectra, since the optics are not corrected past 700nm. The spectra of the Solux lamps was measured by an Ocean Optics USB2000 spectrometer, shown in figure 2(d), where the IR and UV cutoff is clearly seen. The usable range with this filter is $420-680nm$. Unfortunately, we do not have a good UV source at this time. The raw data at the detector shows the coded aperture modulation of the scene, figure 2(c). A 24-frame, 838×853 pixel, 24-channel ($400-700nm$) TwIST reconstruction is shown in figure 2(g), with TwIST parameters $\tau = 0.3$, 70 iterations, and total reconstruction time of 20.7 minutes. A single frame reconstruction with the same parameters, pixel count, and channels is compared to the multiframe reconstruction in figures 2(e) and 2(f).

References

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