DMD-based Compressive Imaging & Spectroscopy

A 1-Pixel Camera & Beyond

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New Acquisition Hardware

- CS changes the rules of the data acquisition game
  - exploits a priori signal/image sparsity information

- Same random projections / hardware can be used for any compressible signal class (generic)

- Simplifies hardware and algorithm design

- Random projections automatically “encrypted”

- Very simple encoding

- Robust to measurement loss and quantization

- Asymmetrical processing (most at decoder)
Conventional Sensing

- The typical sensing/compression setup
  - compress = transform, sort coefficients, encode
  - most computation at sensor (asymmetrical)
Compressive Sensing

- Measure linear projections onto *random* basis where data is *not sparse/compressible*

- Reconstruct via *nonlinear processing* (optimization)
Rice 1-Pixel Camera

**Single Photon Detector**
- Low-cost, fast, sensitive optical detection

Image encoded by DMD and random basis

Random pattern on DMD array

Compressed, encoded image data sent via RF for reconstruction

Image reconstruction
TI Digital Micromirror Device (DMD)

DLP 1080p --> 1920 x 1080 resolution
(Pseudo) Random Optical Projections

- Binary patterns are loaded into mirror array:
  - light reflected towards the lens/photodiode (1)
  - light reflected elsewhere (0)
  - pixel-wise products summed by lens

- Pseudorandom number generator outputs measurement basis vectors ...

![Diagram](image.png)
Rice CI Camera
Image Acquisition

- Original
  - 16384 Pixels
  - 1600 Measurements (10%)

- 65536 Pixels
  - 1300 Measurements (2%)

- 16384 Pixels
  - 3300 Measurements (20%)

- 65536 Pixels
  - 3300 Measurements (5%)

Images of different objects, including a mug with "DSP" and a soccer ball.
CS Low-Light Imaging with PMT

True color low-light imaging:
256 x 256 image with 10:1 compression
CS Imaging in the Infrared

![CS Imaging Infrared Camera Image]

![Graph of Responsivity vs Wavelength]

![Sample Images with Inscriptions: 20% IR, 5% IR]

![Image of a Material Sample with Inscription 'IR']
Dual Visible/Infrared Imaging

Detector: commercial dual-band sandwich photodetector with a Si substrate mounted above an InGaAs substrate
Hyperspectral Mandrill 32x32x64
independent reconstruction of each band
joint reconstruction with a spatial wavelet/spectral Fourier tensor product sparsity basis
joint reconstruction with a spatial wavelet/spectral Fourier tensor product sparsity basis
CS Confocal Microscopy

An imaging technique used to increase contrast and/or to reconstruct 3-D images by using a pinhole to eliminate out-of-focus light

Compressive Sensing vs. Traditional Raster Scan

• 50% of the illumination used in the CS measurement compared to less than 1% used in a raster measurement

• Additionally, CS will make far fewer measurements but will still obtain the same size final image
DMD-based CS Microscope Layout

- **CAM**
- **Relay Telescope**
- **Rotated Mirror**
- **Dichroic Mirror**
- **Collection Lens**
- **Eyepiece**
- **PMT**
- **Imaging Lens (f160)**
- **Objective Lens**
- **Alignment Mirror #1**
- **Alignment Mirror #2**
- **Excitation Filter**
- **Collimating Lens**

**Components:**
- DMD
- Specimen Plane
- Relay Telescope
- Alignment Mirror #1
- Alignment Mirror #2
- Imaging Lens (f160)
- Objective Lens
- Specimen Plane
- DMD
CS Fluorescence Microscopy

- Using the raster scan, the signal quickly drops below our detection limit.

- Compressive sensing we can obtain a high resolution even with decreased detector gain and without the threat of photobleaching.
Three cross-sections are marked in the stress image on the left and displayed below.

Confocal Raman image of a Vickers indent into silicon (10 x 10 μm). The image was calculated by determining the peak position of the Si-Raman line of each measured spectrum. Inset is the corresponding AFM image. (Data courtesy of Witec Instruments GmbH.)

Optical Beam Induced Current Imaging

1. OBIC Theory

- failure analysis to locate electrically active defects such as diffusion, stacking faults, latch-up and leakage in integrated circuits (IC)

- monitor the nonrandom recombination current of the electron-hole pairs generated by a laser as it is scanned across the chip surface.

- variations in currents are converted into variations in contrast to form the OBIC image
Optical Beam Induced Current Imaging

Target: NTE68 (PNP) is a complementary silicon power transistor designed for high power audio, disk head positioners.
CS THz Camera

THz transmitter (fiber-coupled PC antenna)

object mask
random pattern on a planar screen

THz receiver

6cm 42cm 7cm

32 x 32 PCB masks

(a) 1.5cm 1.5cm
(b) 1.5cm
(c) 1.5cm

Object mask

CS recon 300 measurements

CS recon 600 measurements

THz Amplitude

THz Phase

Mittleman Group, Rice University

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THz Camera 2: Sampling in Fourier

Mittleman Group, Rice University
Conclusions

• Compressive imaging
  – a new imaging framework based on compressive sensing
  – exploit a priori image sparsity information
  – based on new uncertainty principles

• Proof of concept: CS camera
  – single sensor element
  – universal, simple, robust image coding
  – imaging beyond the visible
  – hyperspectral
  – confocal microscopy


dsp.rice.edu/cs/camera