A diffractive multispectral image sensor with on- and off-die signal processing and on-die optics in 0.18 micron CMOS

Christopher Thomas, Richard Hornsey
Dept. Comp. Sci. & Eng., York University
Background

• Novel image sensor: on-die diffraction gratings instead of microlenses.

• No extra process steps needed!
Background

• Problem: Image quality bad.

• Solution: Apply deconvolution filters.
  – Wiener
  – FIR
  – Differentiating
Wiener Filter

- Treat imaging as convolution by a point spread function.
- Changes in the PSF with position and wavelength are treated as noise.
Wiener Filter

- Wiener filter performs deconvolution optimally when noise is known.
- Accurate noise model is critical!
Wiener Filter

• **PSF noise:**
  – Standard deviation of desired PSFs.
  – Average of undesired PSFs.

• **Electronics noise:**
  – Fixed pattern noise.
  – Shot noise.
Wiener Filter

PSF

Noise

Wiener
FIR Filter

- Finite Impulse Response (FIR) crops the filter in space domain.
- Allows space-domain implementation of filtering.
- Discards some noise and some signal contributions.
FIR Filter

large

9um

small

3um

1um
Modulation Transfer Functions

raw

1um

FIR

zone plate  pinhole
Differentiating Filter

• Tiny FIR approximates a differentiator.

• Can be built in-pixel.

• MTF, especially pinhole, has 1/f envelope. Differentiator deconvolves.
Modulation Transfer Functions

1μm
FIR

diff

zone plate
pinhole
Differentiating Filter

1um
FIR

diff

ZP large
ZP small
Pinhole
Color Sensing

- MTF for various harmonics vs. wavelength.
- Deconvolved zone plate and pinhole MTFs very sensitive to wavelength.
- Better than 25 nm discrimination possible.
Color Sensing

- Zone plates tuned to R/G/B (red above).
- Deconvolved using red/green/blue isolating filters.
- Sharpens, but inadequate suppression of unwanted colors.
Color Sensing

- Wiener reconstruction (middle) fails due to aliasing and noise.
- Differentiating reconstruction (right) succeeds with severe artifacts.
- To be studied in future works.
Conclusions

• Wiener-derived filters are useful for deconvolving images from this sensor.
• Limit to effectiveness is unsuppressed noise.
• In-pixel differentiator sharpens images but has serious noise problems.
• Color identification is possible for monochromatic point sources.
• Limit to polychromatic imaging is suppression of unwanted color channels.

• Assessment: Useful for niche applications, and can be further improved!
Acknowledgements

- Topaz Technology Inc.
- NSERC
- Centre for Photonics Manufacturing Research
- CMC Microsystems