Micrite

Towards a Sub-100-Micron Distributed Sensor System

Christopher Thomas
Outline

Overview

• Optics
• Deblurring
• Analog to Digital Converter
• Concluding Remarks
Contributions

• System requirements for 100 micron surveillance mote

• Subsystem implementations:
  – Image sensor with on-die optics
  – Deblurring algorithm for on-die optics
  – Log-ramp ADC (ultra-low energy)
Design Goals

• Very small (100 micron) sensor mote fabricated using CMOS-compatible technologies
  – Inexpensive and proven technology.
  – Very large number of devices per wafer.

• Capable of acquiring images for surveillance
  – B/W or colour image acquisition.
  – Digitized with enough fidelity for feature extraction and object tracking.
  – Capable of operating on ambient light power budget.
# Design Specifications

<table>
<thead>
<tr>
<th>Subsystem Area</th>
<th>2000-3000 um² (large)</th>
<th>500-1000 um² (small)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Budget</td>
<td>30 nW (outdoor)</td>
<td>0.15 nW (indoor)</td>
</tr>
<tr>
<td>Charge Storage</td>
<td>1 pF, 0.4 V swing, 0.4 pC charge</td>
<td></td>
</tr>
<tr>
<td>Recharge Time</td>
<td>13-40 us (25-77 kHz) (outdoor)</td>
<td>3-8 ms (125-330 Hz) (indoor)</td>
</tr>
<tr>
<td>Image Dynamic Range</td>
<td>&gt;= 6 bits (raw images)</td>
<td>&gt;= 10 bits (for deblurring)</td>
</tr>
<tr>
<td>Image Pixels</td>
<td>&gt;= 100</td>
<td></td>
</tr>
</tbody>
</table>
Sample Floorplan

- Charge Pump
- Solar Cell
- ADC
- CPU
- Image Sensor
- Capacitor
- LED

100 microns
Outline

• Overview

➢ Optics

• Deblurring
• Analog to Digital Converter
• Concluding Remarks
On-Die Optics

- Images formed by lenses on die, rather than separate component
- Existing project: TOMBO
On-Die Optics

• Metal zone plate optics
• Made using existing process layers
  – No extra steps, no extra cost.
• Side effects:
  – PSF varies with wavelength
  – PSF varies with polarization
Optics Simulations

- Point spread function is a focused spot surrounded by fringes.

- Fringe geometry and brightness varies with wavelength for a given zone plate.

- Off-axis light displaces the spot per thin lens, and changes fringe geometry.

- Polarization effects give an elliptical spot.
Optics Simulations
PSF Measurements
PSF Measurements

• Artifacts:
  – Etalon
  – Deep carriers
  – Leakage
  – Vignetting
  – Narrow gap reflection
PSF Measurements: LED Tests

- No etalon fringes (short coherence length)
- Spot size (FWHM) 0.15-0.20 radian
Outline

• Overview
• Optics

➢ Deblurring
• Analog to Digital Converter
• Concluding Remarks
Deblurring: Method

- Model blurring as noisy convolution.
- Use Wiener deconvolution filter.
- Boosts attenuated spectral components, with boost clamped by expected noise floor.
Deblurring: Simulations
Outline

• Overview
• Optics
• Deblurring

➤ Analog to Digital Converter
• Concluding Remarks
ADC Design

• Using a log-ramp architecture.

• Log scale captures the full image dynamic range with the fewest number of quantization levels.
  – Not the fewest number of comparisons!

• Ramp converter is the time-domain equivalent of flash conversion (one comparison per quantization level).
ADC Design

- Reference voltage is sampled, and capacitively divided to produce a geometric sequence of levels.
- Pixel voltage is assumed to be stable during conversion.
• OTA with N and P differential pairs for rail to rail input.
ADC Simulated Performance

- 0.8 V to 1.2 V supply
- Ramp step noise ~10 mV
  - Expect 5-6 bits equivalent dynamic range
- Bias current 6-8 uA gated, 10-20 uA not
- Minimum step duration 50 ns
  - 1.7-4.7 pC per digitization
- Configurations: 3:1, 2:1, 1:1 dividers
ADC Measurements

[Graphs showing ADC measurements with various parameters and waveforms.]
ADC Measurements

• Operates as-designed at 0.8 V and 1.2 V
• Bias current 6 uA per ADC

• For large reference voltages, first few steps of the ramp are not geometric due to NFET pass transistor

• Experiment output buffer is very slow; DC tests only.
ADC Transfer Functions: 0.8 V

- 3-4+ bits equivalent dynamic range
ADC Transfer Functions: 1.2 V

ADC Transfer Functions (All)

- 3-4+ bits equivalent dynamic range
ADC INL and DNL: 0.8 V

- INL <= 1.3 (typ. < 1)
- DNL <= 0.6
ADC INL and DNL: 1.2 V

- INL <= 1.2 (typ. < 1)
- DNL <= 0.5
Outline

• Overview
• Optics
• Deblurring
• Analog to Digital Converter

➤ Concluding Remarks
Conclusions and Looking Forward

• Outlined a design specification for a 100 micron sensor mote.

• Built and demonstrated a fully-integrated image sensor with on-die metal optics.

• Demonstrated a deblurring and colour separation algorithm based on Wiener filtering.
Conclusions and Looking Forward

• Built and demonstrated an ultra-low-energy log-scale analog to digital converter.

• Future work:
  – Optical transceiver
  – Communications and networking protocols
  – On-mote image processing