Réunion : Projet e-BaCCuSS

An Asynchronous Reading Architecture
For An Event-Driven Image Sensor

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Internet of Things Challenges

Nyquist-Shannon Theorem

+ more data
+ more storage
+ more communications
+ more consumption
Sampling is the success key

• Sampling based on the Shannon-Nyquist theorem
  – Efficient and general theory… \textbf{whatever the signals!}

• Smart sampling techniques
  – \textbf{More efficient} but less general approaches
  – Need a more general mathematical framework
    \footnotesize{F. Beutler, “Sampling Theorems and Bases in a Hilbert Space”, Information and Control, vol.4, 97-117, 1961}

• Sampling should be \textbf{specific to signals and applications}
Image Sensors

- Today not too much work for lowering IS consumption
- Some works for reducing the dataflow
- Non-uniform sampling techniques in 1D

- Could we apply similar techniques in 2D?

Outline

• Conventional Image Sensors
• Event-Driven Pixel
• Asynchronous Image Sensor
• The Proposed Asynchronous Image Sensor
• Simulation Results
• Conclusion and Perspectives
How does an Active Pixel Sensor (APS) works?

- Global Reset Phase
- Global Integration time
- Analog-to-Digital Converter

![Diagram showing the operation of an Active Pixel Sensor](image-url)
Conventional Image Sensor principles

- Based on **Photo-sensitive pixels**
- All pixels are read in sequence

- Larger the sensor
- Higher the throughput (fixed frame rate)
- Higher the ADC consumption

The **ADC** is the main contributor of power consumption
Limitations of an Active Pixel Sensor

• Fixed Frame Rate
• High and redundant Dataflow
• Fixed Integration Time
• Limited Dynamic Range
• High Power consumption

We can do better!
Towards an Event-Driven IS in 2D

- Fully sequential reading
- High Throughput (worst case)
- Need of data compression
  - (Yue, Wu, and Wang 2014)
  - (Amhaz et al. 2011)

- Event-based reading
- Low Dataflow
- Management of spatio-temporal redundancies
Spatial and Temporal Redundancy

I. Temporal Redundancy:
Pixels in two video frames that have the same values in the same location.

II. Spatial Redundancy:
Pixels values that are duplicated within a still image.
Changing the paradigm in a realistic manner

I. Remove the **ADC** to limit power consumption
   - ✓ Use Time-to-Digital Conversion (TDC)

II. Reduce the **dataflow** without reducing the frame rate
   - ✓ Suppress spatial and temporal redundancies
   - ✓ Use Event-Driven logic (Asynchronous)
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Replacing the Analog-to-Digital Conversion by the Time-to-Digital Conversion

Changing the way we read and encode the pixel information
The Event-Driven Pixel

• Based on Event-Detection

• Time to first spike encoding (Rullen & Thorpe 2001)

  1-level crossing sampling scheme

• Low Throughput

  All read data is relevant
Event-Driven Pixel behavior

- One Sampling Level Scheme

- The Pixel initiates the reading phase once an event is detected

- Pixel Self Control Mode
What are the advantages of using an Event-Driven Pixel

- Unique **Integration Time** per pixel
- Optimal **Dynamic Range**
- Adaptive **Frame Rate**
- **Low Power Consumption**
- Adaptive sensitivity depending on luminosity conditions
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Event-Based Readout Circuit
State of Art

I. Non-deterministic:
• Requires an Arbiter
• Power Consumption
• Timing Error
• Higher area
  (arbiter size increases exponentially with the array size)

II. Deterministic:
• No Arbiter
• Fully asynchronous design (with handshake)
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Pixel Reading Sequence

Détection d’événement -> Initialisation locale

Requête de lecture -> Acquittement
Communication asynchrone à 4 phases

Horodatage (Time Stamping) -> Suppression des redondances spatiales
Asynchronous Readout Architecture

- Asynchronous Pixel behavior (~45 transistors)
- Self-Resetting Pixel
- Time to Digital Conversion

- High Temporal Resolution
- Two Memory Blocks
- Full Asynchronous Digital Design
How do we suppress **Spatial Redundancy**?

4 x 4 image sensor

(Darwish, Fesquet, and Sicard 2014)
(Darwish, Sicard, and Fesquet 2014)
Same Reading Request Group, Different Instant of Reset

- For each pixel, we:
  - Save Instant of request
  - Calculate the Integration Time using the last instant of reset

- No spatial redundancy

- Reduced image data flow
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Register-Transfer-Level Simulation

MATLAB generates the reading request flow

RTL Level Reading system

MATLAB constructs images using Integration Time values

Resultant Image Evaluation:
1. SSIM: Structural Similarity \((Wang \ et \ al. \ 2004)\)
2. PSNR: Peak-Signal-to-Noise Ratio

MATLAB generates the reading request flow

RTL Level Reading system

MATLAB constructs images using Integration Time values

Pixel integration time value
Sequential Pixel Requests

MATLAB Algorithm

Reading System (RTL Level)
## Simulation results

### Low data flow rate

- **High PSNR** (greater than 40 dB)
- **High SSIM Values** (greater than 0.8)

<table>
<thead>
<tr>
<th>Picture Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSIM</td>
<td>0.869</td>
<td>0.943</td>
<td>0.925</td>
<td>0.978</td>
</tr>
<tr>
<td>PSNR</td>
<td>43.23 dB</td>
<td>41.97 dB</td>
<td>42.98 dB</td>
<td>43.22 dB</td>
</tr>
<tr>
<td>% of the original data flow</td>
<td>15.5 %</td>
<td>4.23 %</td>
<td>0.47 %</td>
<td>3.88 %</td>
</tr>
</tbody>
</table>
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Conclusion:

- **1-level crossing sampling** in 2D
- Adjustable resolution and dynamic range (Time Stamping)
- Adaptive architecture to light conditions (Sampling Level)
- Image **data flow reduction** (Gain > 94%)
- **Event-driven** digital circuitry

Perspectives:

- Image sensor fabrication and test
- **Directly process** the sparse image data flow
Non-uniform sampling is the future of digital universe!

Thanks for your attention