Sampling Circuits for Non-Uniform Sampling and Processing for Low-Power Purpose

Event-Based Control, Circuits and Processing towards Ultra-Low Power Consumption

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Outlines

• Non Uniform Sampling
• Filtering with NUS signals
• Pattern Recognition
• NUS in 2D
• High-Level Synthesis for NUS
• Conclusion
Internet of Things Challenges

+ more data
+ more storage
+ more communications
+ more consumption

Nyquist-Shannon Theorem
Sampling is the success key

- Sampling based on the Shannon-Nyquist theorem
  - Efficient and general theory… whatever the signals!

- Smart sampling techniques
  - More efficient but less general approaches… for specific signals!

  - Need a more general mathematical framework


- Sampling should be specific to signals and applications
What can we do?

Uniform and Synchronous

Non Uniform and Event-driven (Asynchronous)
What to expect?

- **Activity reduction** for many signals (1 to 3 orders of magnitude)
- **Signal-dependent sampling** technique
- Dynamic activity selection (impossible if synchronous)
- **Direct processing of the non-uniform samples** (Filtering, spectral analysis, etc.)
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Sampling differently

Uniform sampling

- Respect the Shannon theorem
- Instants exactly known
- Information: $T_{\text{sample}}, \{i_k\}$
- In an ADC: Amplitude quantization
- Many useless samples

Non uniform sampling

- “Level-crossing sampling” (LCSS)
- Amplitudes exactly known
- Information: quanta, $\{dti_k\}$
- In an A-ADC: Time quantization
- Only useful samples
A-ADC testchip

Microphotography of the A-ADC
In CMOS 130 nm technology from STMicroelectronics

E. Allier et al., 2003

Lowering in one step the storage, the processing, the communications and the power consumption!
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LCSS for filtering

\[ O_n = \sum_{k=0}^{N-1} h_k \ast i_{n-k} \]

The instants are synchronized

Classical digital convolution product incompatible with non uniformly sampled signals

Find a digital equation using the information contained in the time intervals
Async. Convolution Product

Asynchronous convolution product:

\[ o(t) = \int_{-\infty}^{+\infty} h(\tau) i(t - \tau) d\tau \quad \Rightarrow \quad o(t_n) = \int_{-\infty}^{+\infty} h_n(\tau) i_n(t_n - \tau) d\tau \]

Asynchronous convolution algorithm:

\[
\begin{align*}
o_n &= \sum dt_{\text{min}}(di_{n-k}, dth_j) \times i_{n-k} \times h_j \\
dto_n &= dti_n \\
\text{if } dt_{\text{min}} = dti_{n-k} &\quad \text{then } dth_j = dth_j - dti_{n-k} \\
&\quad \quad \text{if } dt_{\text{min}} = dti_{n-k} \\
&\quad \quad \text{then } dth_j = dth_j - dth_j \\
&\quad \quad \quad \text{if } dth_j = dti_{n-k} \\
&\quad \quad \quad \text{then } k = k + 1; j = j + 1.
\end{align*}
\]
Experimental setup

Asynchronous FIR Filter + A-ADC.

Aeschlimann et al., 06
Beyrouthy et al., 11

Synchronous ADC

Asynchronous ADC
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A successful experiment

- Context of the medical implants
- Activity patient measurements

T. Le Pelleter et al., 13
L. Fesquet et al., 14
E. Allier et al. 05

Experiments based on real physiological signals (recorded on the patients)
Pattern Recognition

- Pattern: **two peaks with opposite signs**
- A **peak** is considered as a **subpattern** (sequence detection)
Pattern Recognition

- Finding a **threshold** that separates the **density function** of true and false subpatterns
- **Thresholds** determined with the **ROC curve**
- **Optimal thresholds are generated** by the **farthest** ROC points from the **diagonal**
- **Only 4 thresholds**
What we learned with the experiment

• **Be more specific** to signals and applications
• **Non-general approach**, but **reproducible**

With the medical

• No pre-processing
• **Less than 1% of data** compared to the uniform sampling
• **3 orders of magnitude reduction** on power

• **Non-uniform sampling** well adapted to sporadic signals
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Towards an event-driven ADC in 2D

- Fully sequential reading
- High Throughput (worst case)
- Need of data compression
- Event-based reading
- Low Throughput
- Management of spatio-temporal redundancies
Pixel behavior

- Based on event-detection
- 1-level crossing sampling scheme
- A unique integration time per pixel
- Time to first spike encoding

Adjust the image sensor sensitivity = High Dynamic range
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High Level Synthesis

- Needs for Quick prototyping (HW) of control or signal processing chains
- Evaluate signals and applications in Matlab (SPASS)
- Determine the levels for LCSS
- Automatically generate ADCs
- Automatically refine the Matlab model to target event-based circuits (Asynchronous High-Level Synthesis)
Design flow for ultra-low power
Non-uniform sampling (level-crossing) and Asynchronous circuits

- Operator sizing
- Memory bounds

Algorithm Refinements
Algorithm (Matlab)
Levels placement

Application specific conditions and targets

Signal Database

Algorithm (C)

Cross Optimization?

High-Level Synthesis

Existing tools + Asynchronization

Netlist (Proc. Unit)

Netlist (A-ADC)

- Signal Processing
- Machine Learning

E-BaCCuSS, Oct. 19, 2015
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General Conclusion

• Lesson 1: **Determine** the most efficient sampling!
• Lesson 2: Fit well **Event-Driven Circuits** (asynchronous)
• Lesson 3: **Ultra-Low Power**

• Less samples means:
  – Less computation, less storage, less communications,
  – less power

A greener approach of digital processing and more generally of the IoT
Non-uniform sampling is the future of digital universe!

Thanks for your attention