ADVANCES IN EDGE EMBEDDED SENSOR BASED COMPUTING

IoT & IA, innovation en santé, environnement
Advances in Edge Embedded Sensor based Computing

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Our goals:

- Embedded Monitoring, Detection, Alert Generation and Recording
  - Very high acquisition frequencies (i.e. Inia: 500kHz)
  - Very long recording time: (i.e. strict natural reserves)
Our research
Advances in Edge Embedded Sensor based Computing

- **Advances in sensors and dataloggers**
  - Qualilife Sound recording system.
  - Qualilife: a joint-protocol embedded system

- **Advances in low power wake-up systems**
  - Low power wake-up system based on frequency analysis.

- **Future works**
  - High level embedded signal analysis.
  - Low power high level primitives for nano-edge computing.
  - Indoor localization for embedded sensors.
Advances in sensors and dataloggers
Qualilife Sound Recording System

- Qualilife-Sound: high performance audio extension board
  - Up to 5 synchronous channels with adjustable sampling rate
    - Up to 2 Msps in 2 channels configuration
    - Up to 800 Ksps on 5 channels configuration
  - Analog front end with adjustable gain: $\frac{1}{4}$ - 1 - 4 - 8 - 16 – 64
  - High performance anti-aliasing filter.
  - Analog pre-filtering: available upon request
  - Direct HDD USB recording
High performance: Qualilife versus TASCAM DR-40

- Bandwidth and aliasing (input frequency sweep 1Hz – 1MHz): Qualilife is far better.

- Some noise present (50-70 kHz): removed in incoming version
Advances in sensors and dataloggers
Qualilife Sound Recording System

- An example of application:
  - 2D Source tracking using 2 microphones:
    - 2 channels - 1Msp/s sampling
    - Distance between microphones: 21 cm
    - 3 hand claps
      - In front
      - 40°
      - 90°
    - Microphones
      - Omnidirectional
      - Wide-band and ultrasonic
      - High Gain
    - Ref: uSMIoT
Advances in sensors and dataloggers
Qualilife Sound Recording System

- An example of application:
  - 2D Source tracking using 2 microphones

- Angle: 0°
  - TDOA: 0 samples

- Angle: 40°
  - TDOA: 477 samples -> 0.477ms -> 15 cm

- Angle: 90°
  - TDOA: 625 samples -> 0.625ms -> 21 cm
Advances in sensors and dataloggers
Qualilife: a joint-protocol embedded system

- Qualilife: a modular joint protocol data logger
  - Recording management
    - Scheduling, synchronization and time-stamping
    - Mass storage on USB devices
    - Low power management
    - BLE smartphone communication:
      Facilitate recording control in harsh environments.
  - Extensions daughter boards
    - Advanced sensor development.
      - Qualilife Sound is one of the daughter boards.
      - Embedded algorithms for detecting patterns.
    - Arduino compatibility
Advances in sensors and dataloggers
Qualilife : a joint-protocol embedded system

- Qualilife Light : light sensors extension board
  - Four high sensitivity sensors for night light monitoring
    - Light pollution studies
  - UV sensor
  - Embedded algorithms : flash counting...
Advances in sensors and dataloggers
Qualilife : a joint-protocol embedded system

- **Qualilife-Move : movement acquisition**
  - Extension board for synchronizing up to 4 inertial motion sensors and magnetic compass and a GPS.
  - Embedded algorithms in development :
    - Detection or characterization of vibrations.

- **Qualilife-Detector : Chemical pollution detection**
  - Environmental conditions :
    - Hygrometry, pressure and temperature
  - Chemical pollutions :
    - CO₂, Nox, PM 2.5 and PM 10, Ozone
Qualilife joint protocol experiments

Coupling daughter boards together with joint protocols:

- Acoustic and movement: ex. bees experiments
- Acoustic and light measurement: impact of light pollution on animals behaviors.
- Acoustic and chemical pollution: impact of everyday indoor and outdoor pollution on the real estate prices.

Other ideas are welcome!
Advances in sensors and dataloggers

Qualilife: a joint-protocol embedded system

- Limitations:
  
  Embedded + High frequency recording + long time recording = difficult

- SMIoT Qualilife recording system:
  
  - 1 Msps/16bits channel / 4 channels -> 28 Go/h
  - Power = 5W -> 0.12kWh/day
  - In one year:
    - 44kWh = 3 tons of lead batteries !!!
    - 250 HDD of 1 TB !!!

- Not acceptable for long term embedded recording.
Reducing power consumption in embedded environmental systems

- Too much useless data storage.
  - Costs a lot of money in embedded data storage
  - Needs to be often emptied

- Too much energy consumption in embedded devices.
  - Too short recording periods.
  - Need for long life expensive batteries.

Generating real time alerts:

- Necessary for human interventions

- Requires:
  - Reliable alerts generators
  - Reliable wireless long range low data rate transmissions
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- **Future works**
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  - Low power high level primitives for nano-edge computing.
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Introducing a low to higher power signal analysis chain:

- **Objective**: having the power consuming parts of the data logger in sleep mode most of the time.

Introducing a hierarchical data analyzer and recording system using low power signal wake-up systems: PhD. Manon Fourniol.

Diagram:
- **Ultra low power**: Signal Trigger
  - Mixed analog-digital electronic circuits
- **Low power**: Signal analysis
  - Filtering and simple pattern analysis
- **Standard power**: Signal classification
  - Deep learning, cloud computing

Diagram flow:
- Input signal to Signal Trigger
- Data transmission from Signal analysis to Signal classification
- Analysis wake-up to Alerts
- Classification wake-up to Classification
- Data storage and advanced alerts
Advances in low power wake-up systems

- A microcontroller wake-up system based on frequency analysis
Advances in low power wake-up systems

- A microcontroller wake-up system based on frequency analysis

Capacitor voltage is proportional to input signal frequency

\[ U_C = \int_0^t \frac{I_C(t)}{C} dt = \int_0^t \frac{I_0}{C} U_m(t) dt = \frac{I_0}{C} * N * T_m = \frac{I_0}{C} * \frac{F_S}{F_{TrCP}} * T_m \]
A microcontroller wake-up system based on frequency analysis

- **Results:**
  - Power consumption: 0.6mW excluding the microphones
    - 10,000 times less than the Qualilife recording system!
    - Active 3 years on a single 12V – 1.2Ah lead battery.
  - Very selective in frequency detection:
    - 5kHz bandwidth for a 100kHz signal detection.
  - Limited to frequency analysis
    - No pattern detection
    - Limited to very low power detection of high frequency signals.
**Advances in low power wake-up systems**

- **An analog wake-up system based on frequency analysis**
  - Same system in analog components
    - Avoid using a microcontroller
    - Each component is optimized
      - For power consumption and speed
      - i.e. CSS555C : 5uA each
  - Results : nearly finished...
    - Expected power consumption :
      - About 60uW
      - 10 times lower than uC implementation
      - Active 3 years on a single coin CR2032 battery cell
Advances in low power wake-up systems

- A silicium wake-up system based on frequency analysis
  - Same system in silicium implementation
    - To be done with Edith Kussener and Hervé Barthelemy
Our research

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Future works
High level embedded signal analysis

- Wake-up detector is used for waking up a signal analysis embedded system
- Signal analysis can implement:
  - Digital linear filters
  - Advanced filters (Kalman...)
  - Wavelets transforms
  - Neural networks
- Not ultra-low power, especially at high sampling rates!
Future works
Low power high level primitives for nano-edge computing

- A nano-edge computing graal!

Finding ultra-low power primitives for doing high level signal processing

- What are the most fundamental high level signal processing primitives?
  - FFT?
  - Wavelet?
  - Pattern recognition?

- **Correlation** is a very important one:
  - Close to human brain mechanisms

\[
C_{sr}(\tau) = s(t) \otimes r(t) = \int_{-\infty}^{\infty} s(t)r^*(t - \tau)dt
\]
Implementing correlation in ultra-low power mode:

- Digital implementation is very power consuming:
  - Too many operations

- Analog implementation: Preliminary work
  - Delay can be done by propagation using delay lines
  - Multiplications: using an analog multiplicator or a linear to log converter.
  - Integrator: using a LP filter having a large time constant compared to the period of the signal.
Analog implementation of the correlation function:

- Each output of LP filter at each stage of the delay line is close to the value of the correlation function in nT.
Improvements:

- Long delay correlations requires a long delay line
  - Not a problem for L and C.
  - Too much power drawn if each node have its own multiplier.
  - A solution: using a (few) multiplexer(s) and a microcontroller for multiplexing delayed signals.
Further improvements:

- Multi-resolution correlation
  - Adding a analog buffer and a resistor allows to make multi-resolution
    - Closing 4 switches -> average of 4 signals
    - Closing 2 switches -> average of 2 signals

- Add a multi-resolution functionality to the correlation network
  - Similar to hierarchical layers in deep learning
  - Raise architecture - algorithm questions issues

Future works:

Low power high level primitives for nano-edge computing