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Design of a flexible analog-to-feature converter for smart acquisition of biological signals

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Motivation : In the context of **wireless sensors**, power consumption is a key aspect. The energy consumption of wireless communication systems represents a significant part of the total consumption. Compressed sensing permits to **reduce** the amount of acquired samples but it needs a very complex signal reconstruction step. **Analog-to-feature** conversion is an acquisition method thought for IoT devices, in order to **increase their battery life**. The aim is to build a generic A2F converter in order to acquire **low frequency** signals (ECG, EEG...). The proposed A2F converter is based on non-uniform wavelet sampling.

Keywords : Non-uniform wavelet sampling, Analog-to-feature converter, Feature selection

Analog to Feature converter

Classical approach : Acquisition based on Shannon's theorem

→ Too many samples to acquire and transmit.

Analog to Information conversion : Acquisition based on compressed sensing

→ Reduces the number of samples but needs a very **complex** signal reconstruction step.

Analog to Feature conversion : Acquisition based on compressed sensing

→ The reconstruction algorithm is replaced by a **machine learning based classifier**, able to detect anomalies in the signal and thus to **only transmit the classification result**.



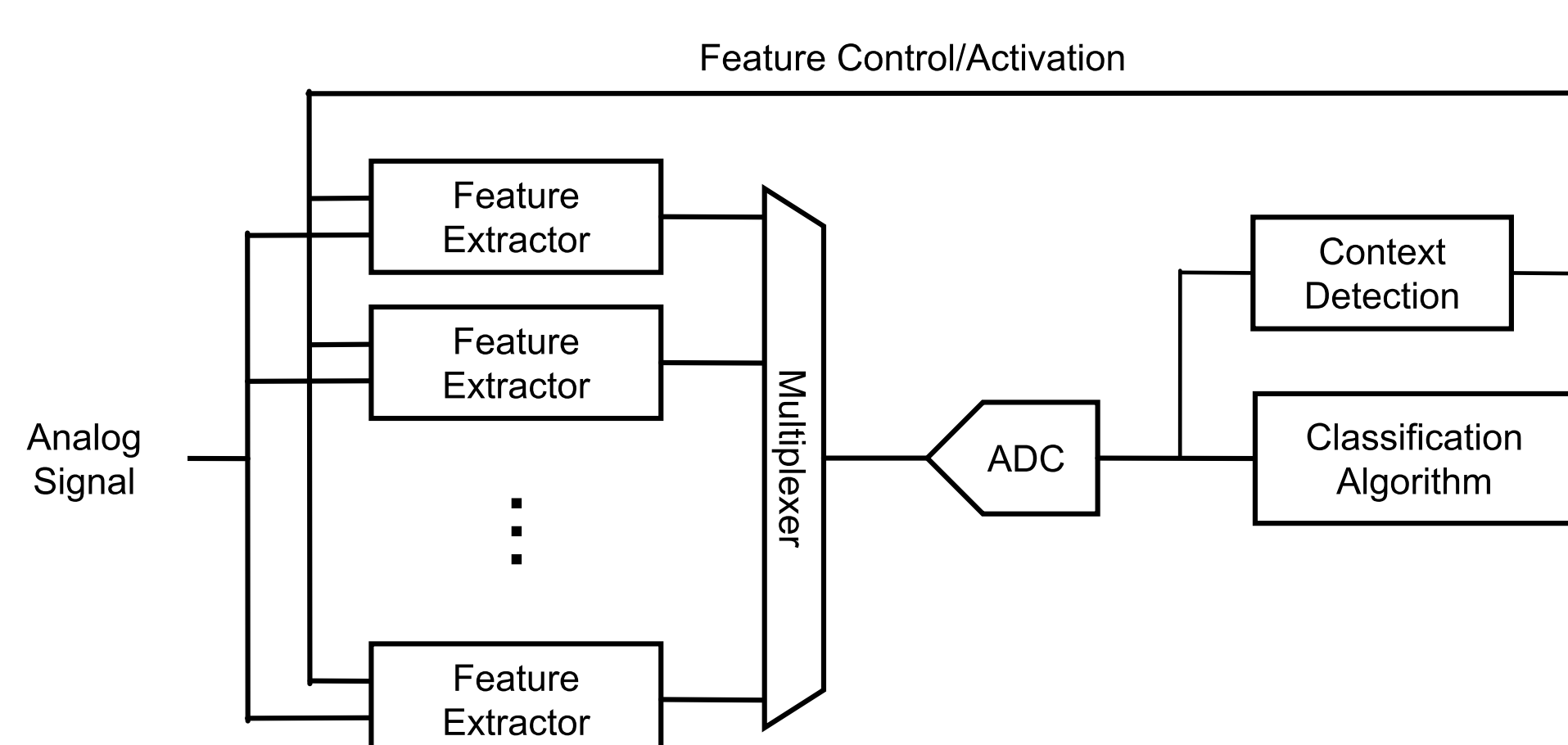
Compressed sensing

The aim of compressed sensing is to **decrease the amount of samples** compared to sensors using classical approach based on Shannon's theorem. Let x be the N -dimensional signal vector that we want to acquire. Let s be the K -sparse representation of x , i.e., the vector s has K non-zero values in a known basis. Let y be the M -dimensional vector of compressed measures.

$$y_{M \times 1} = \begin{bmatrix} \text{Sensing matrix } \phi \\ M \times N \end{bmatrix} \times \begin{bmatrix} \text{Sparsifying Matrix } \psi \\ N \times N \end{bmatrix} \times s_{N \times 1}$$

Reconfigurable Architecture

- **Analog** feature extraction
- Analog to digital conversion of features
- **Anomalies detection** with machine learning algorithm



- Context detection allows to :
 - **Activate, disable or reconfigure** features extractors depending on the signal type (ECG, EMG, EEG...)
 - **Adjust the precision** to perform a binary classification or a more precise classification in order to know the type of anomaly.

The reconfigurable implementation permits to **adjust the power consumption** to the minimum for a given input signal and a given application.

Non-uniform wavelet sampling (NUWS)

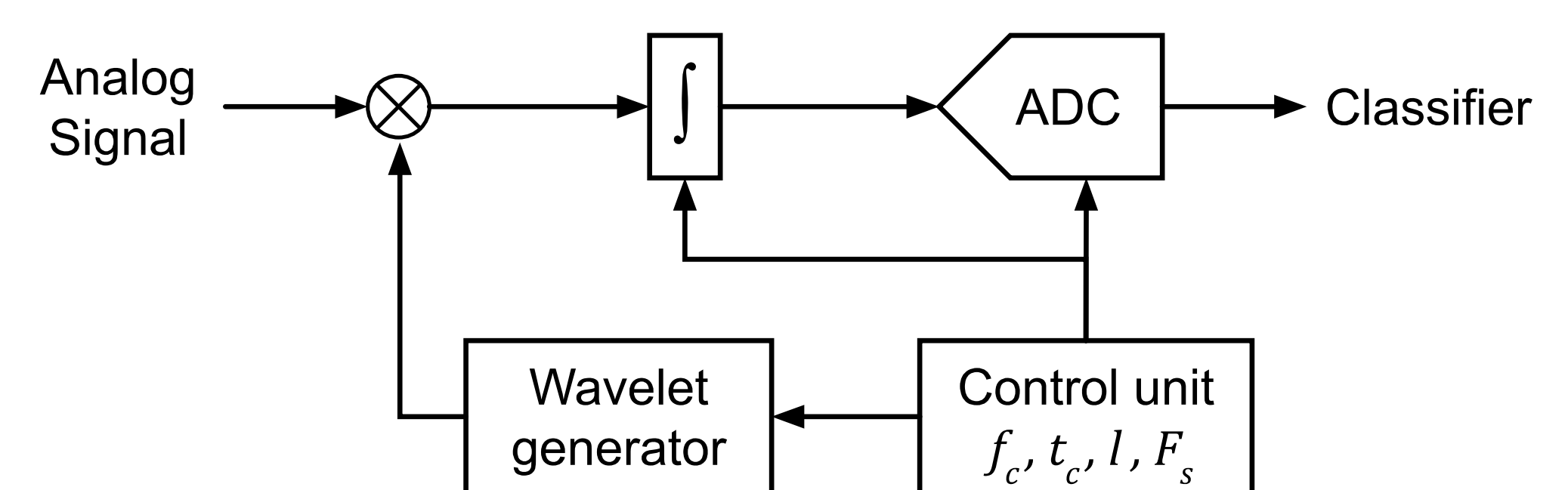
The operating principle of NUWS is to transform the analog signal $x(t)$ into a wavelet frame and then acquire a small set of wavelet samples. The incoming analog signal is mixed with a wavelet and then the result is integrated over the support of the wavelet

Benefits of wavelet transform :

- Permits to obtain information both in **time** and **frequency domain**
- Has three degrees-of-freedom (sample time instants, wavelet bandwidth and center frequency) → **Adaptive extraction**

$$Wf(a, b) = \frac{1}{\sqrt{a}} \int_{\mathbb{R}} f(t) \cdot \Psi^* \left(\frac{t-b}{a} \right) dt$$

- Ψ is the mother wavelet (Haar wavelets, Gabor wavelets,...) and Ψ^* the complex conjugate of Ψ
- $a > 0$ is the scale factor
- $b \in \mathbb{R}$ is the temporal shifting.



Feature Selection

The wavelet frame contains a **huge amount of wavelets**, so we have to find solutions to select a small set of wavelets that can be **efficiently generated** and that provides **good classification performance**.

Filter methods (Fisher score, Similarity, Information Gain ...)

- ✓ Permit to obtain a solution **quickly**
- ✗ Provide **non-optimal** solutions

Wrapper methods (Sequential search, Genetic algorithm, ...)

- ✓ Provide **optimal** solutions for a classification method
- ✗ **Slower** than filter methods, extremely **expensive** to run for data with a large number of features

Solution : Suppress redundancy by using a filter method and so to reduce the size of the wavelet frame and then use a wrapper method to find the best solution.

We propose an architecture based on non-uniform wavelet sampling, to design a flexible analog-to-feature converter for biological signal acquisition and anomaly detection.

Future work will focus on implementing features selection algorithms to obtain different wavelet sets. This selection step will enable to specify the characteristics of the wavelet generators.