Design optimization of flexible analog-to-feature converter for smart sensors

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Introduction

Motivation: The fast development of the Internet of Things (IoT) and Wireless Sensor Networks (WSN) leads to the need for **new context-aware sensors**. One of the main requirements for such sensors in emerging applications is a long lifetime. Thereby, the **reduction of energy consumed during data transfer from sensor to aggregator** is a viable solution for increasing the autonomy of sensors. One can achieve this by adopting a novel data acquisition technique, such as **Analog-to-Feature (A2F) conversion**.

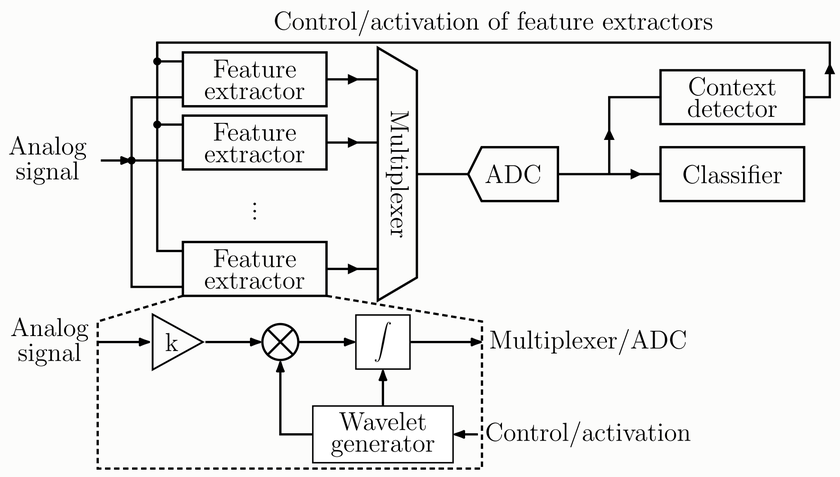
Objective: Design of a generic, reconfigurable A2F converter for different low-frequency signals.

Analog-to-Feature conversion

A2F conversion allows to reduce the number of acquired samples by extracting the useful features directly in the analog domain and using them as inputs for Machine Learning (ML) algorithms for further classification at sensor or aggregator level.

Generic, reconfigurable A2F converter's architecture ⇒

- NUWS-based analog domain **feature extraction**
- analog-to-digital conversion
- application-specific **binary / multiclass classification**
- context detection for **extractors' reconfiguration** (depending on signal or classification type)



Non-Uniform Wavelet Sampling [2]

- mixes the analog signal with tunable wavelets (Haar, Gabor...) prior to integration
- allows to obtain temporal and frequency information
- provides several degrees of freedom (frequency, temporal position, support size)
- requires feature selection to determine a reduced set of relevant features due to a large number of possible wavelets

⇓

Two-stage feature selection [1]

- Filter method (Fisher Score, Information Gain) - fast pre-selection, reduces redundancy of feature set
- Wrapper method (SFS) - long evaluation of remaining features, provides an adapted solution for a given classifier

Simulation Results

Arrhythmia detection using ECG signals

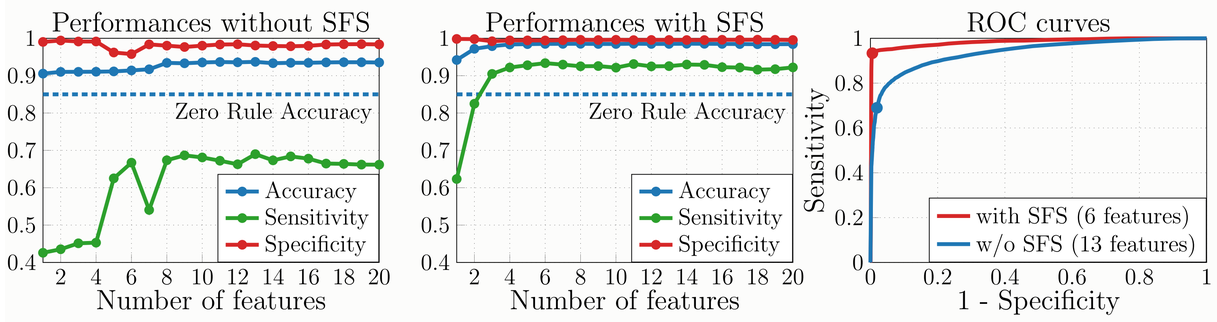
Proposed approach is beneficial over A2I conversion and conventional sampling [1] → **transition to more suitable and advanced software tools** (reimplementing ML algorithms using Python and TensorFlow instead of MATLAB® tools, allowing for more complicated and efficient Neural Networks)

Configuration:

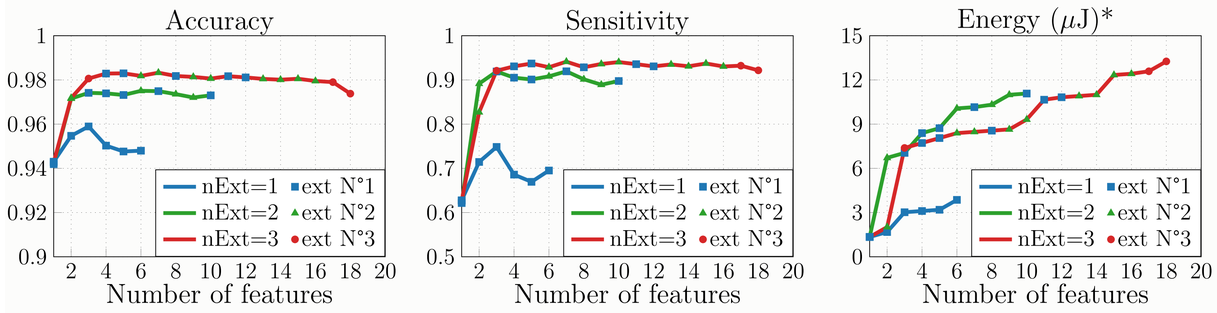
- MIT-BIH Arrhythmia database (48 recordings of 30 min each, sampled at 360 Hz)
- NUWS with Haar wavelets (square functions taking values ±1, 0)
- Information Gain filter method for feature pre-selection
- supervised learning (70/30% proportion between learning and test sets)
- analysis window = 256 samples per one annotated heartbeat
- NN binary classifier (one hidden layer of 10 neurons, 1500 training epochs)

Results:

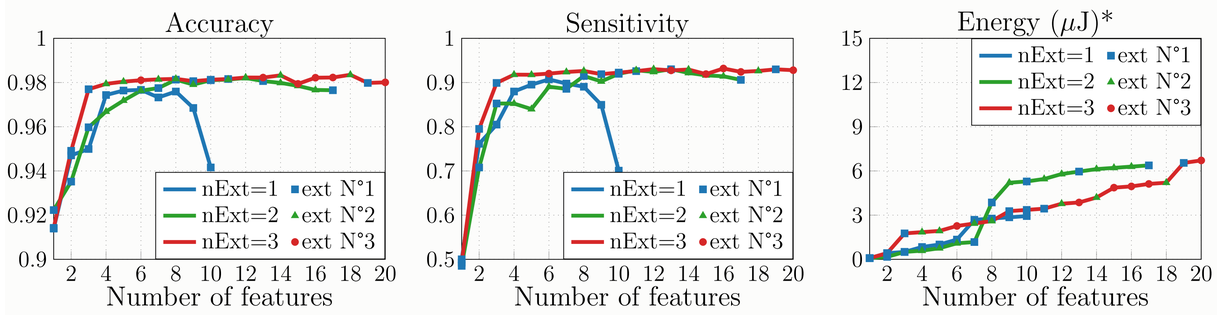
- **Impact of SFS algorithm**



- **Adapted SFS** (limits the maximum number of parallel extractors)



- **Optimized SFS** (accounts for feature extraction energetic cost)



*Estimation with the state-of-the-art circuit components and synthesized digital wavelet generator [1].

Conclusions

- Haar wavelets: high performances, simple converter's implementation
- adapted SFS: 7 features with 8.5 µJ consumption for 98.33% accuracy
- optimized SFS: 8 features with 2.6 µJ consumption for 98.17% accuracy

Another application is explored to show the genericity and reconfigurability of the proposed A2F converter and determine its parameters required for the complete circuit design and chip fabrication ⇒ **Human Activity Recognition** is a promising candidate.

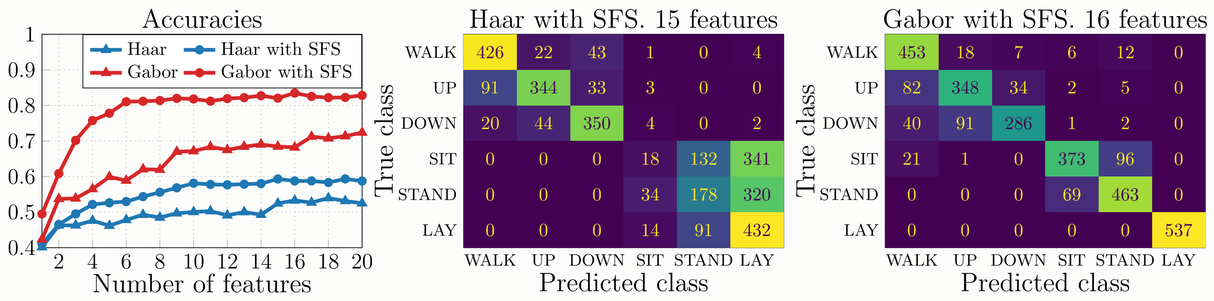
Human Activity Recognition using inertial sensors

Configuration:

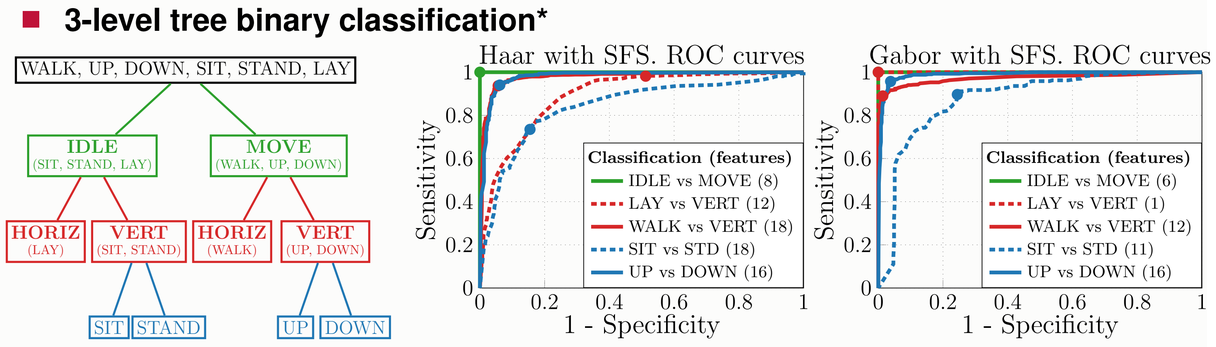
- UCI HAR database (3-axial accelerometer and gyroscope signals from waist-mounted smartphone, sampled at 50 Hz) with 6 activities of daily living (WALKING, UPSTAIRS, DOWNSTAIRS, SITTING, STANDING, LAYING)
- NUWS with Haar / Gabor wavelets (generated from all 6 signals)
- Information Gain filter method for feature pre-selection
- supervised learning (70/30% proportion between learning and test sets)
- analysis window = 128 samples per one annotated activity fragment
- NN classifier (one hidden layer of 10 neurons, 1500 training epochs)

Preliminary results:

- **Multiclass classification**

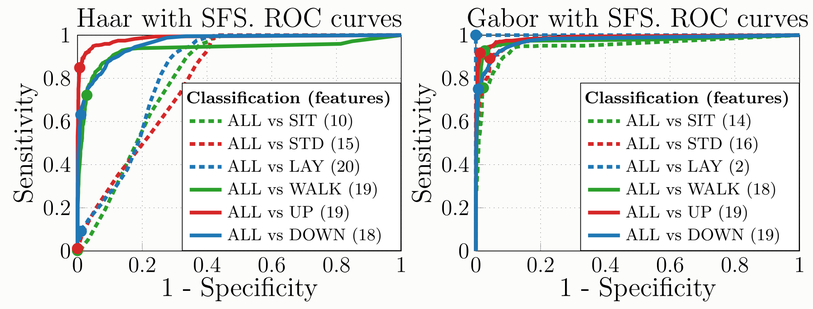


- **3-level tree binary classification***



*Training and test sets are formed independently at each level.

- **All-vs-one binary classification**



Conclusions

- Gabor wavelets: better overall results, especially for idle activities' distinction
- selection of signals for feature extraction is to be explored more thoroughly
- more sophisticated NN classifier might be required to improve the performances

Bibliography

[1] Antoine Back. 2022. "Conception et intégration d'un convertisseur analogique-paramètres flexible pour les capteurs intelligents".

[2] Michaël Pelissier and Christoph Studer. 2018. "Non-uniform wavelet sampling for RF Analog-to-Information conversion". DOI: 10.1109/TCSI.2017.2729779.

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