Digital Filter with Confidence Input

Axel Heim, Martin Hoch

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Introduction

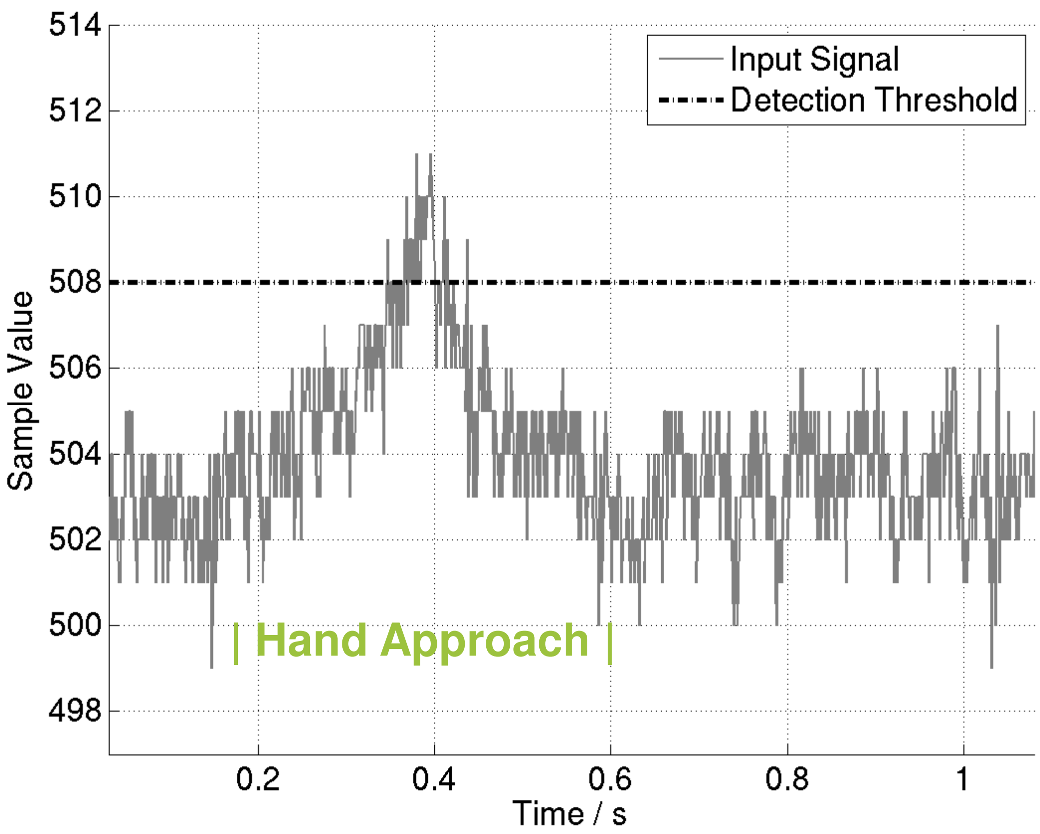
Signal Estimation

Sampling faster than information changes

→ Digital Signal Enhancement

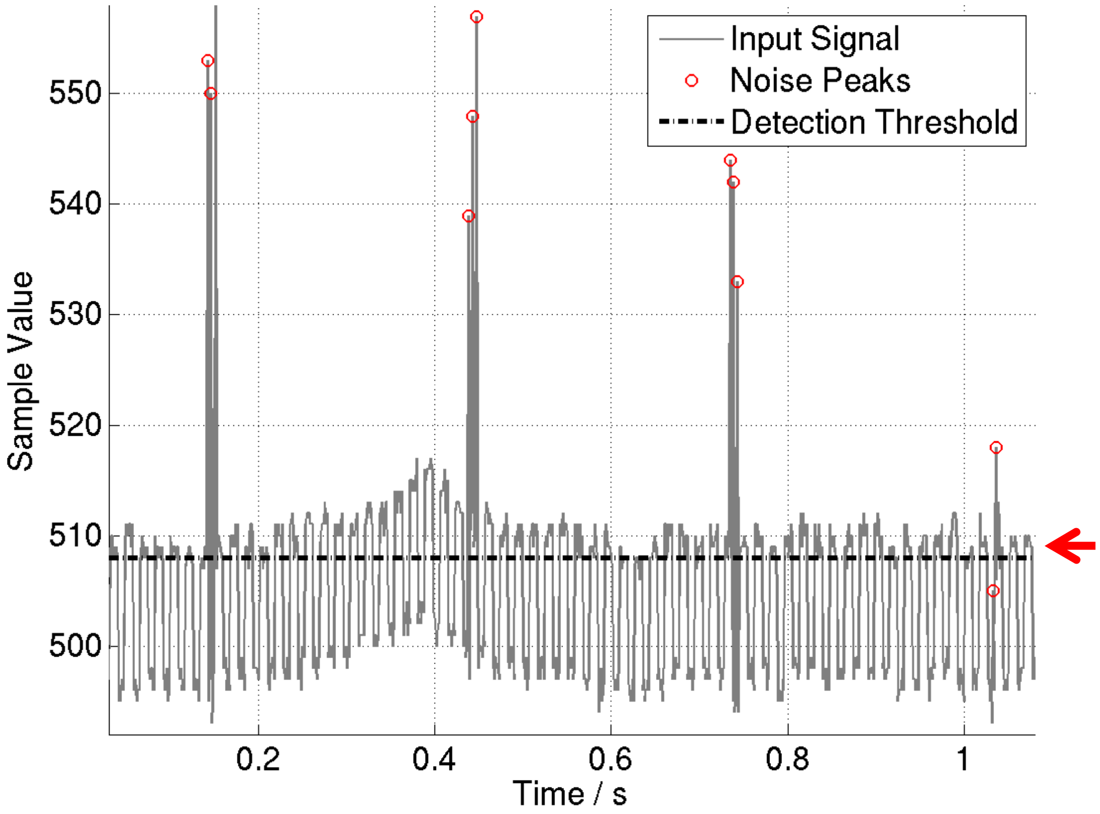
Introduction

Example: Capacitive Proximity Detection



Introduction

Example: Capacitive Proximity Detection



- Noise peaks / bursts
- 60Hz noise (plus harmonics)

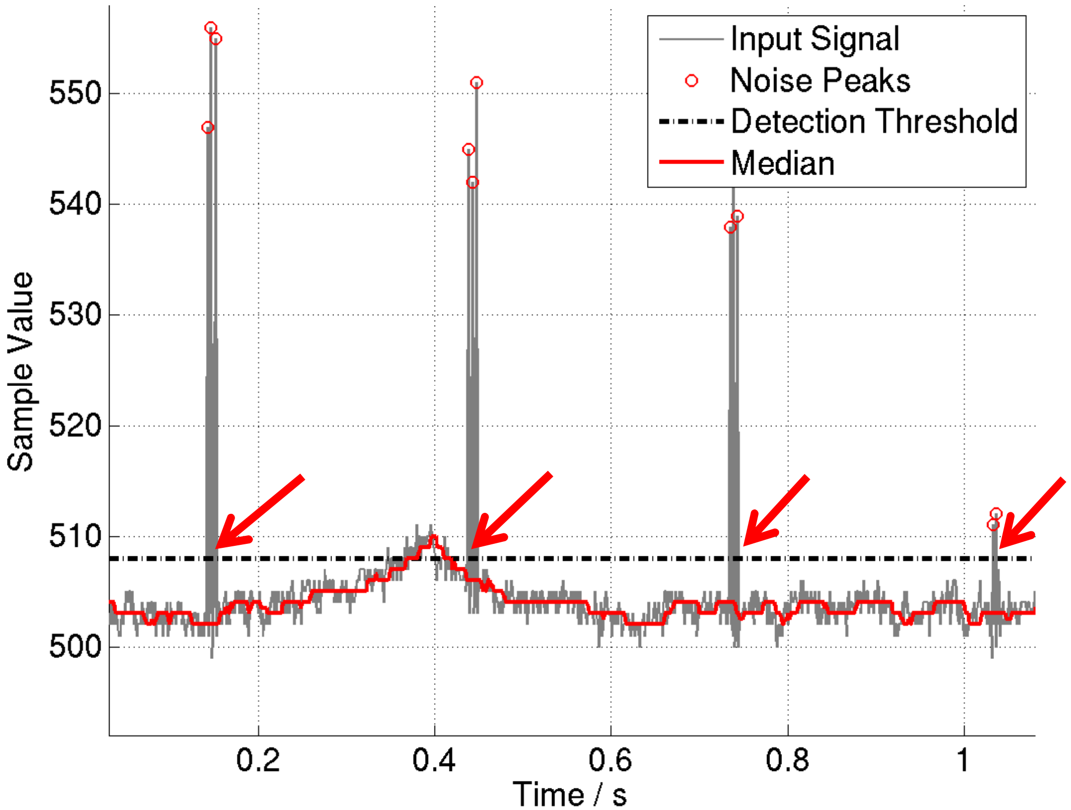
False Detections(!)

Outline

- **Introduction**
- **State-of-the-Art**
- **Digital Filter with Confidence Input**
  - Definition & Goals
  - Principle Approach
  - Filter Function & Spectrum
  - Properties
  - Performance
- **Summary**

State-of-the-Art

Example: Capacitive Proximity Detection

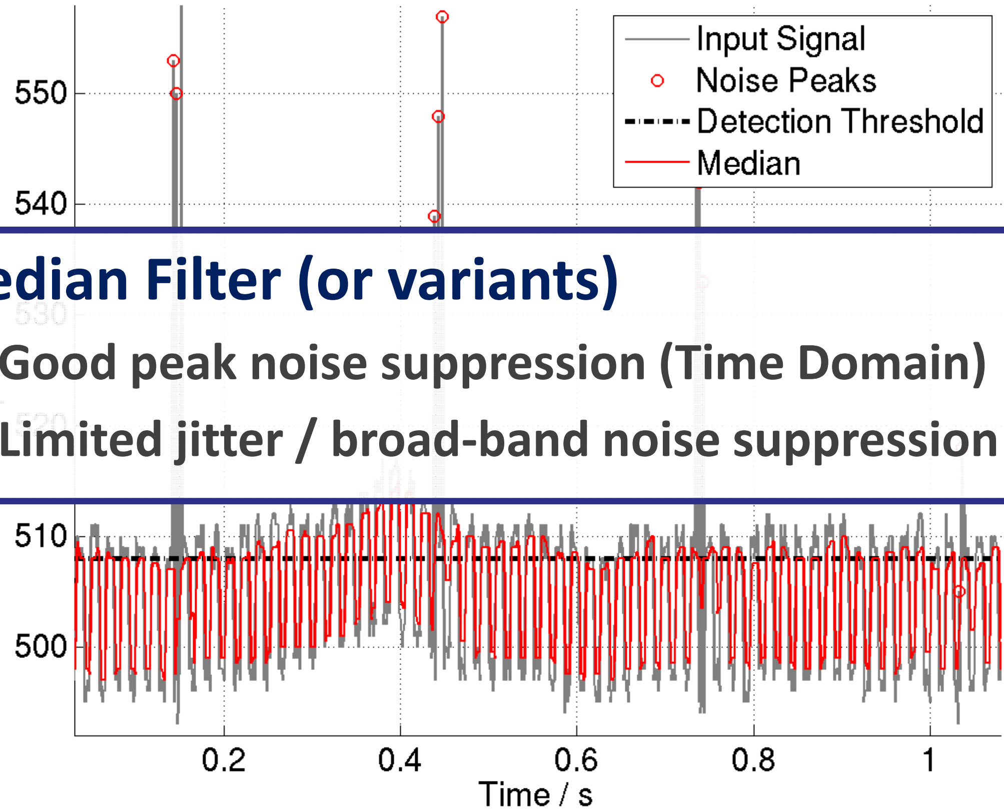


Standard Test:
IEC 61000-4-4
(Burst Noise)

False Detections(!)

State-of-the-Art

Example: Capacitive Proximity Detection



Median Filter (or variants)

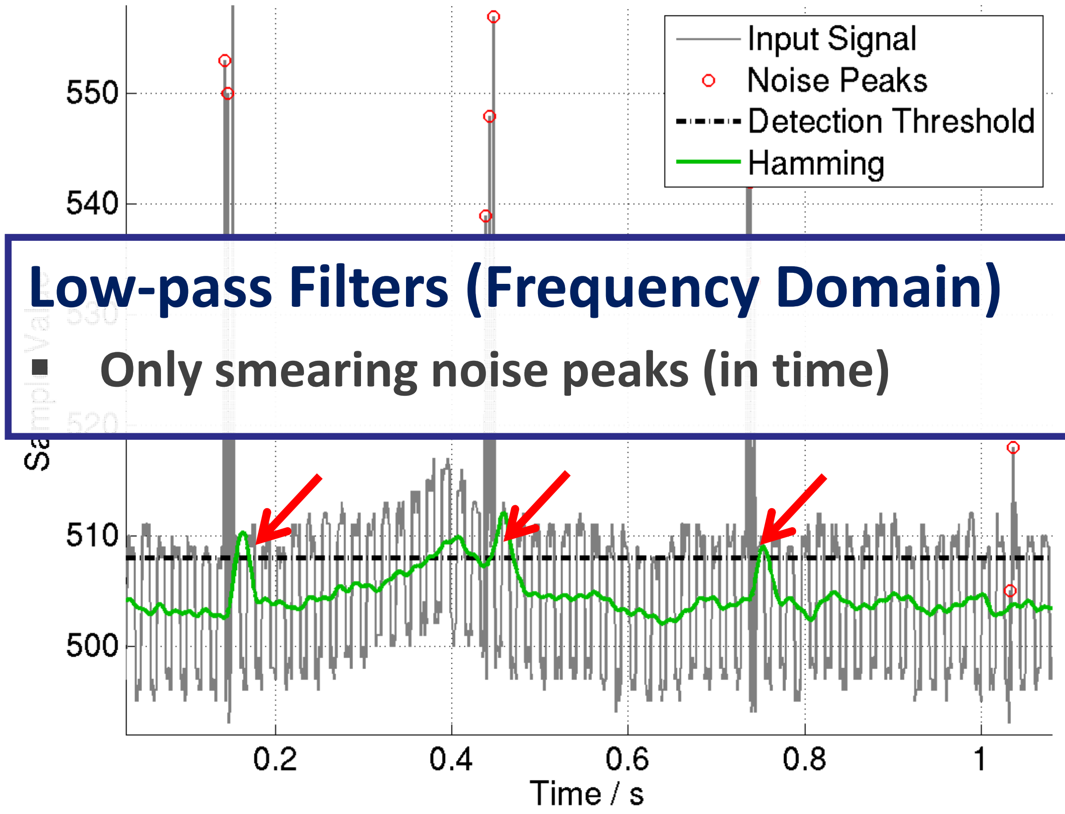
- Good peak noise suppression (Time Domain)
- Limited jitter / broad-band noise suppression

additional 60Hz noise (plus harmonics)

False Detections(!)

State-of-the-Art

Example: Capacitive Proximity Detection



Low-pass Filters (Frequency Domain)

- Only smearing noise peaks (in time)

False Detections(!)

State-of-the-Art

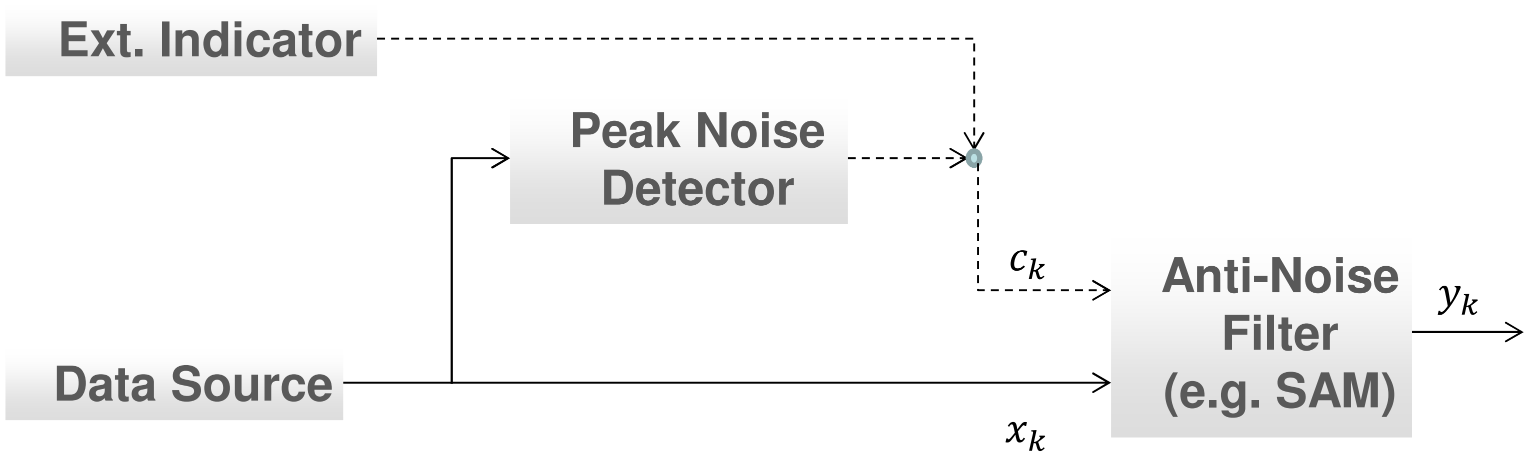
How to suppress both peak noise and 60Hz noise?

Known Approach: Selective Arithmetic Mean (SAM)

- Average over all non-peak-noise (non-`outlier’) samples in a time window
- Suppressing peak noise
- Smoothing the input signal
- Without outliers: Noise suppression characteristics (frequency domain) is inferior to other state-of-the-art low-pass filters

Confidence Input

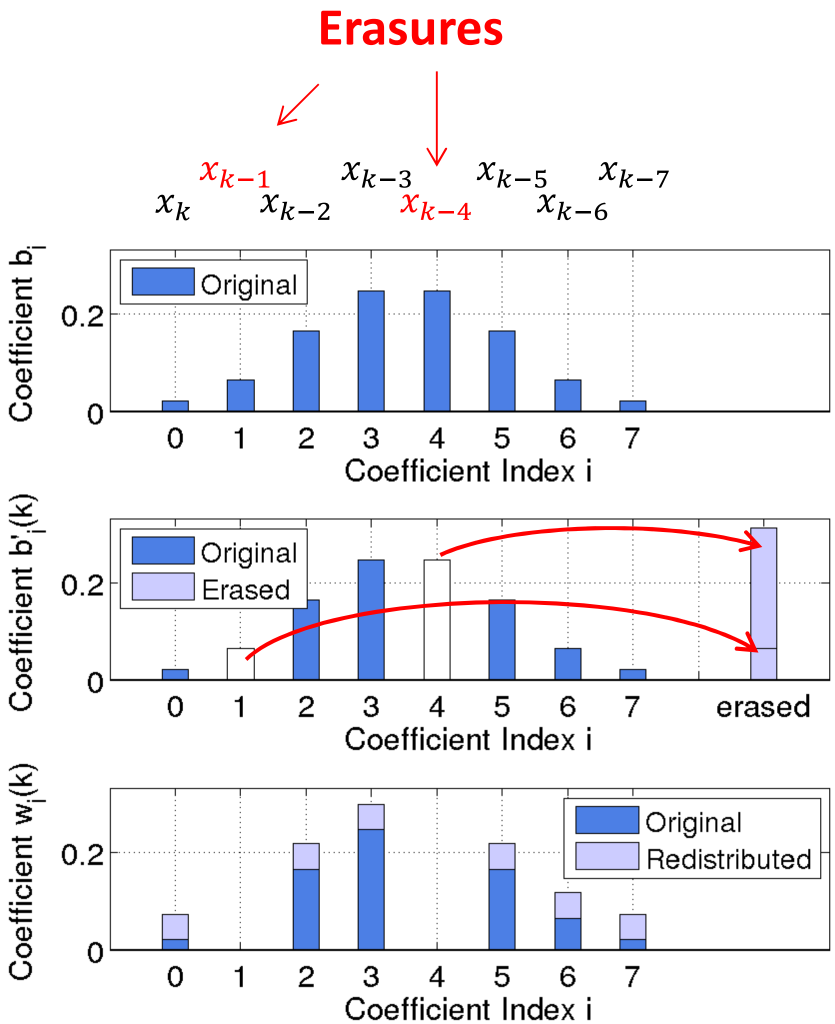
- Each input sample x_k associated with confidence $c_k \in \{0,1\}$
  - $(x_k, c_k = 1)$ → Full confidence in x_k , standard case
  - $(x_k, c_k = 0)$ → No confidence in x_k , do not use x_k (*Erasure*)



Development Goals

1. Without Erasures, filter shall be FIR low-pass with specified filter function $\boldsymbol{b}$
2. Erasures, e.g. erased noise peaks, must not contribute to filter output
3. Maintain constant filter gain at DC

Filter Adaptation



Goal 1: Choose desired filter function for use without Erasures

On runtime: Each input sample is assigned to a filter coefficient.

$$y_k = \sum_{i=0}^{N} b_i \cdot x_{k-i}$$

Goal 2: Erasures must not contribute to filter output

Set corresponding filter coefficients to Zero.

Goal 3: Maintain constant DC gain

Sum weights of coefficients assigned to erased samples (here: b_1 and b_4), and distribute evenly among the coefficients assigned to non-erased samples.

formally speaking ...

$$(1) \quad y_k = \sum_{i=0}^{N} x_{k-i} \cdot w_i(k)$$

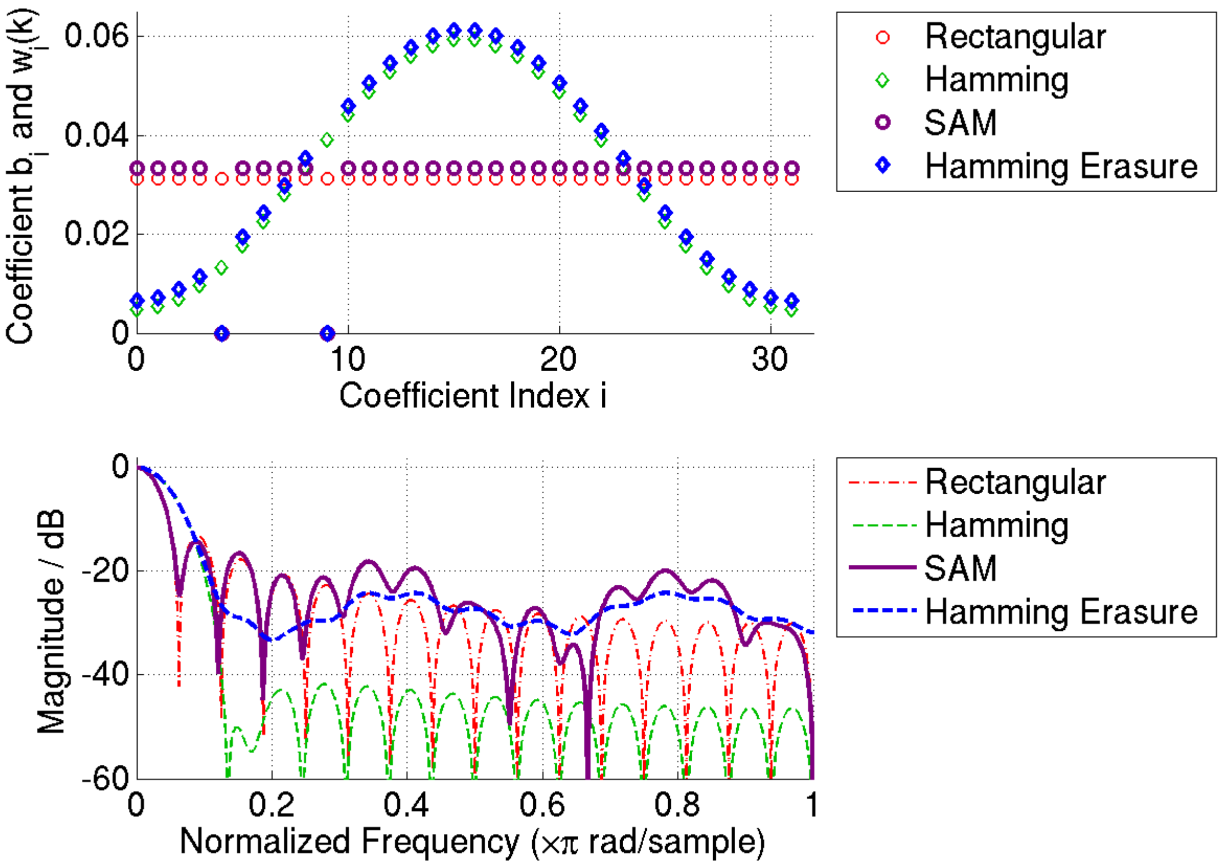
$$(2) \quad w_i(k) = c_{k-i} \cdot \left(b_i + \frac{1}{\sum_{j=0}^{N} c_{k-j}} \cdot \underbrace{\sum_{j=0}^{N} \left(1 - c_{k-j}\right) \cdot b_j}_{\text{erased weight}} \right), \qquad c_k \in \{0,1\}$$

$$(3) \quad \sum_{i=0}^{N} w_i(k) = \sum_{i=0}^{N} b_i$$

DC gain maintains constant

Filter Function & Spectrum

Example: Two Erasures

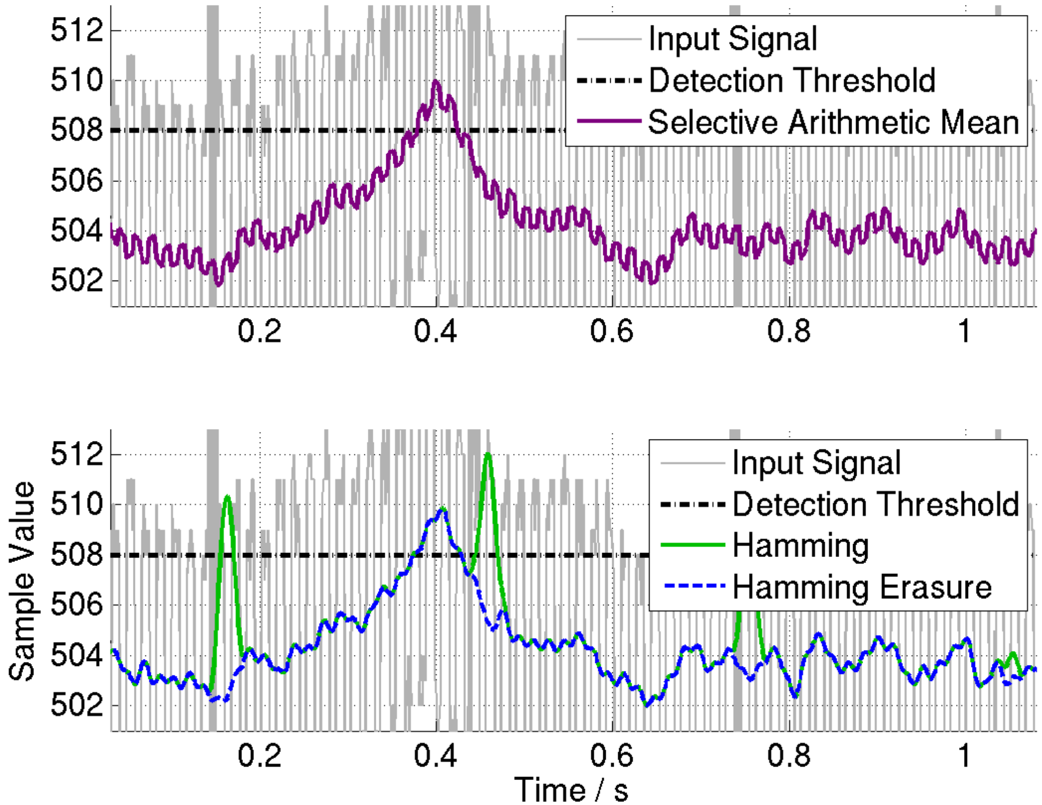


Properties

- All filter coefficients b_i should have the same sign, e.g. Triangular window, Hamming window
- The higher the filter order of $\boldsymbol{b}$, the less affected is the filter characteristic by Erasures
- Gradually adapting to number of Erasures
- Exception handling needed if all input samples are Erasures
- No start-up transient at filter's turn-on time

Performance

Example: Capacitive Proximity Detection



Selective Arithmetic Mean poorly suppresses 60 Hz noise

Hamming filter only smears noise peaks

Hamming Erasure filter suppresses 60 Hz noise *and* noise peaks

Summary & Conclusions

- Standard FIR low-pass filter designs modified with additional confidence input yielding capability to suppress peak-noise in time domain by time-variant adaptation of filter coefficients
- Applicable to any measurement signal sampled faster than its information changes (capacitive sensors, pressure/temperature sensors, …)
- No tuning parameters
- Simple → Robust

→ **Filter provides generic means to suppress both broad-band and peak noise**

Thank you for your attention.

Questions?