Signal Processing and Adaptive Filtering: Overview and Applications

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My Background

Education

- (2003–2008) Bachelor's Degree in Electronics Engineering
- (2008–2009) Especialization in Mixed-Signal IC Design - Cadence Systems
- (2010–2012) Master's Degree in Electronic Systems
- (2012–2016) Doctorate in Electronic Systems

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Areas of Expertise

- Signal Processing Algorithms → Adaptive Filters
- Electronic Systems: microcontrollers, FPGAs, DSPs
- ASIC design
- Nanosatellites (CanSats)

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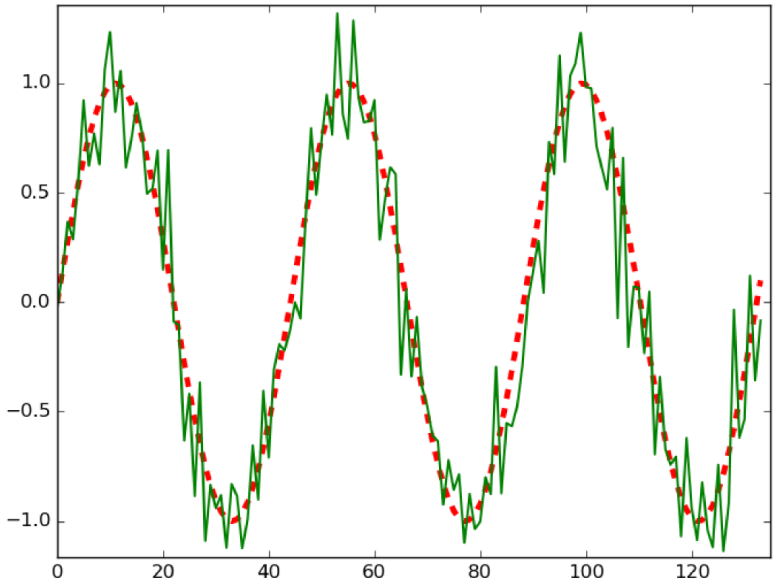
Signal Processing



What is signal and what is noise?

- Goal: retrieve information of interest (signal).
- Signal to be recovered: application dependent.
- A filter (estimator) is necessary.

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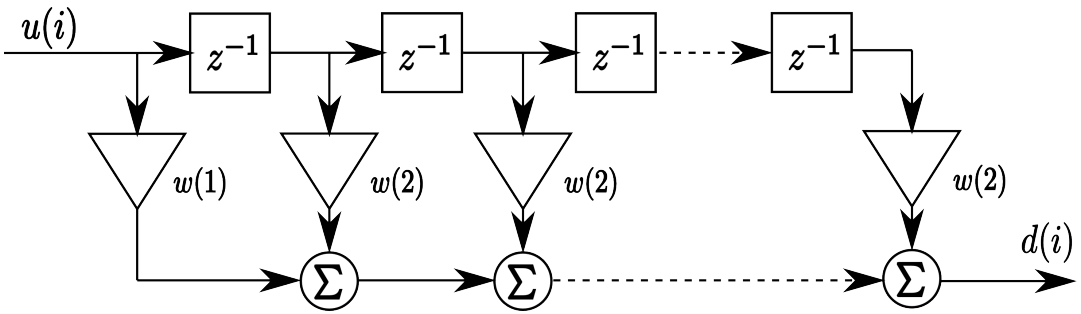
FIR Filters

$$w = \begin{bmatrix} w(1) \\ w(2) \\ \vdots \\ w(M) \end{bmatrix}$$

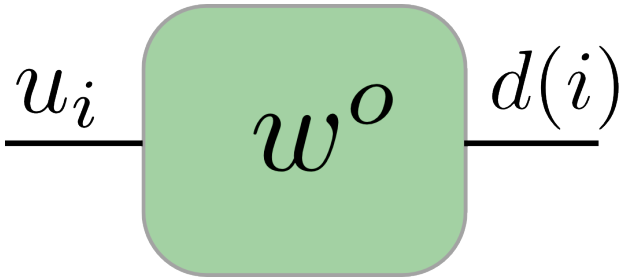
- Finite Impulse Response (FIR) Filters
- Many systems can be described by an array of coefficients
- Coefficients = Taps



Tapped Delay Line

Source: www.xes-inc.com

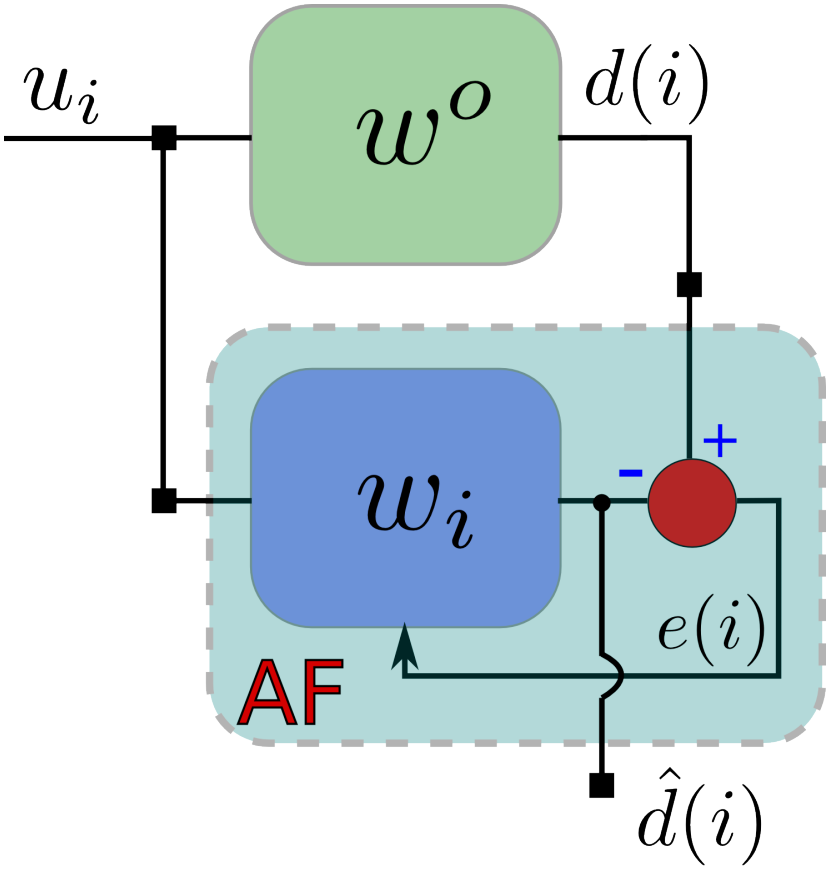
Application 1 - System Identification



Plant to be modeled

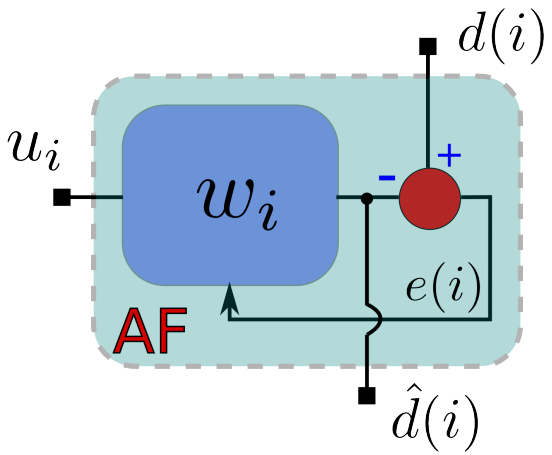
- Classical application in signal processing.
- $u_i^T w^o = d(i)$
  w^o is an unknown array, u_i is an array of input samples, $d(i)$ is the output.
- One can use an estimator to model the plant.

Application 1 - System Identification



- Adaptive (electronic) Filter as the estimator.
- $d(i)$ is compared to $\hat{d}(i)$.
- Error signal $e(i)$ is used to update the estimate for w^o.
- If AF is well designed, $w_i \approx w^o$, $i \to \infty$.

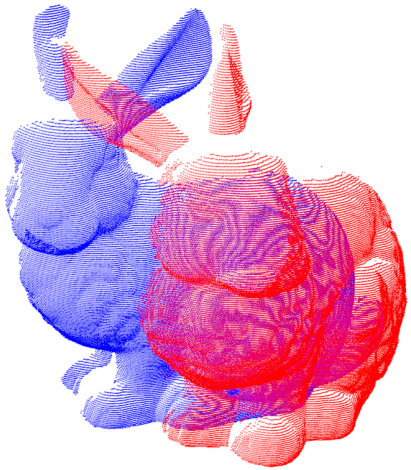
Adaptive Filter



- Building block of artificial intelligence.
- It does not need any previous knowledge of the environment statistics.
- Example of update equation (Least-Mean Squares Adaptive Filter):

$$\boxed{w_i = w_{i-1} + \mu u_i \Big(d(i) - u_i^T w_{i-1} \Big)} \qquad (1)$$

Application 2 - Alignment of 3D Shapes



Point Clouds

- 3D Point Clouds: Target (Red) and Source (Blue).
- They have regions in common.

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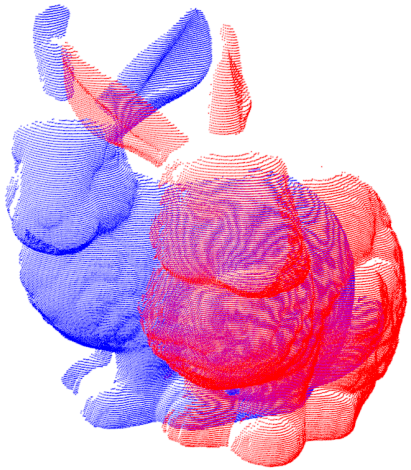
Application 2 - Alignment of 3D Shapes



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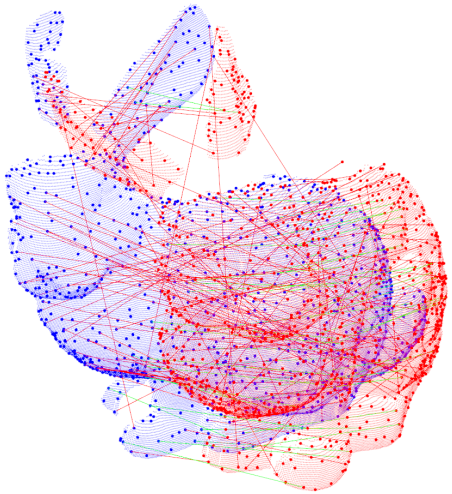

Establishing correspondences

- 3D Point Clouds: Target (Red) and Source (Blue).
- They have regions in common.

- Identifies the intersection between them.
- True and false correspondences.

Application 2 - Alignment of 3D Shapes

- K correspondence points.
- Rigid transformation? *Least-squares problem*

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$$\mathcal{F}(\mathbf{R}) = \frac{1}{K}\sum_{n=1}^{K} \|y_n - \mathbf{R}x_n\|_2^2, \text{ subject to } t = \bar{y} - \mathbf{R}\bar{x}. \quad (2)$$

$\mathbf{R}$: 3×3 rotation matrix, t: 3×1 translation vector.

- Use *adaptive filter* to estimate $\mathbf{R}$ and t.

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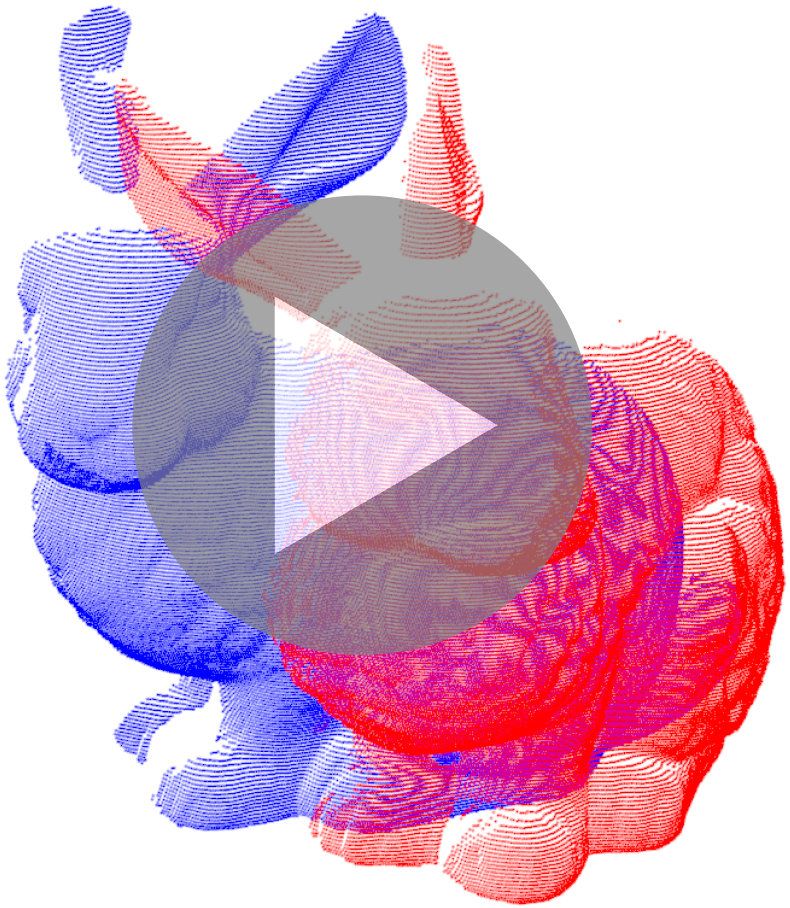
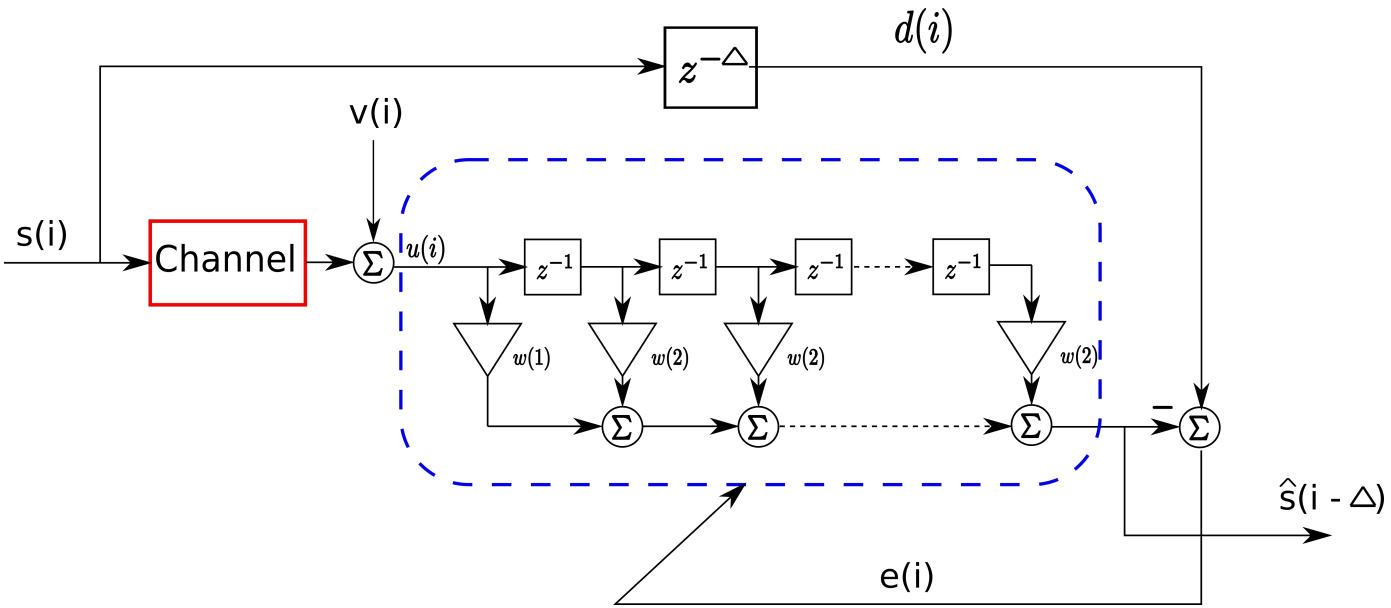


Application 3 - Adaptive Channel Equalization



- Goal: manipulate the channel frequency response.
- The equalizer taps can be estimated via an adaptive algorithm.

$$w_i = w_{i-1} + \mu u_i \left(d(i) - u_i^T w_{i-1} \right)$$

Thanks for your attention!

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