

ML Estimation of the Resampling Factor

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WIFS'2012. 2nd-5th December 2012, Tenerife (Spain)

Problem

- Resampling factor estimation for tampering detection.
- Previous works, based on frequency analysis, present some drawbacks:
 - For reliable results, a large amount of samples is needed.
 - Presence of periodic patterns misleads the detectors.
 - Windowing effect impairs the performance when slight transformations are employed.

Contributions

Theoretical analysis:

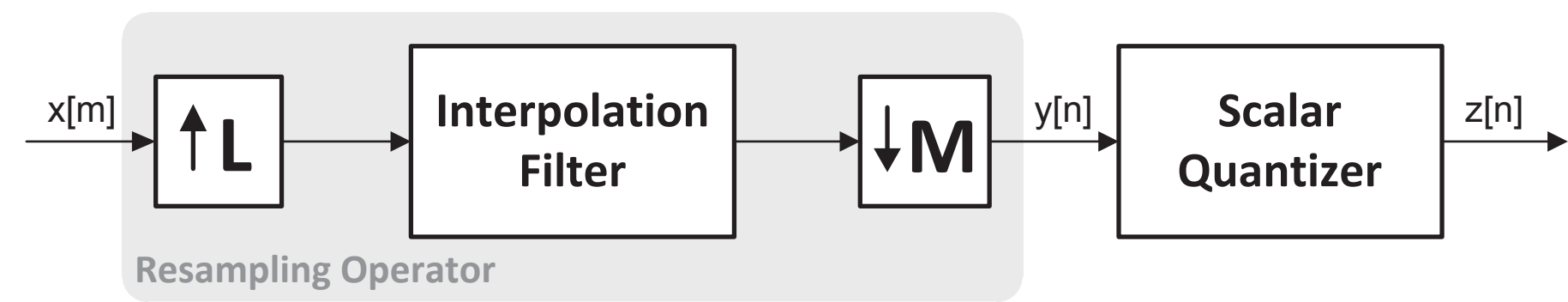
- Relying on the rounding operation applied after resampling, an approximation of the likelihood function of the quantized resampled signal is obtained.

New method for resampling factor estimation:

- Applicable to 1-D signals, piecewise linear interpolation and resampling factors larger than 1.
- The three drawbacks of the frequency-based methods are sorted out with the proposed estimator.

Resampling Operation Description

Block diagram representation:



Change of the sampling rate of a 1-D signal $x(n)$ by a resampling factor $\xi \triangleq \frac{L}{M} > 1$.

Mathematical formulation:

$$y(n) = \sum_k x(k)h\left(n\frac{M}{L} - k\right),$$

where $h(t)$ with $t \in \mathbb{R}$ represents the linear interpolation filter:

$$h(t) = \begin{cases} 1 - |t|, & \text{if } |t| \leq 1 \\ 0, & \text{otherwise} \end{cases}.$$

The quantized version of the resampled signal $y(n)$, denoted by $z(n)$, is expressed as

$$z(n) = \begin{cases} Q_{\Delta}\left(x\left(\left\lfloor n\frac{M}{L} \right\rfloor\right)\right) \left(1 - \text{mod}\left(n\frac{M}{L}, 1\right)\right) + x\left(\left\lfloor n\frac{M}{L} \right\rfloor + 1\right) \text{mod}\left(n\frac{M}{L}, 1\right), & \text{if } n \notin L\mathbb{Z} \\ x\left(n\frac{M}{L}\right), & \text{if } n \in L\mathbb{Z} \end{cases},$$

where $Q_{\Delta}(\cdot)$ represents a uniform scalar quantization with step size Δ (i.e., the same one used for the original signal).

ML Approach to Resampling Estimation

Goal: Given a vector of observations $\mathbf{z}$, we want to know the resampling factor ξ applied to the original vector $\mathbf{x}$.

MLE:

$$\hat{\xi} = \arg \max_{\xi > 1} f_{\mathbf{Z}|\Xi}(\mathbf{z}|\xi).$$

The joint pdf $f_{\mathbf{Z}|\Xi}(\mathbf{z}|\xi)$ can be obtained by processing all the distinct and disjoint blocks of L samples from the vector $\mathbf{z}$, i.e.,

$$f_{\mathbf{Z}|\Xi}(\mathbf{z}|\xi) \approx \prod_{j=0}^{N/M-1} \int_{\mathbb{R}^M} f_{\mathbf{Z}_{Lj}|\mathbf{X}_{Mj}}(\mathbf{z}_{Lj}|\mathbf{x}_{Mj}) d\mathbf{x}_{Mj},$$

where $\mathbf{Z}_{Lj}$ and $\mathbf{X}_{Mj}$ (and also their corresponding outcomes) are vectors of size L and M , respectively.

Derivation of $f_{\mathbf{Z}|\Xi}(\mathbf{z}|\xi)$

- If z_i is a visible sample, thus deterministic:

$$f_{Z_i|X_k}(z_i|x_k) = \delta(z_i - x_k).$$

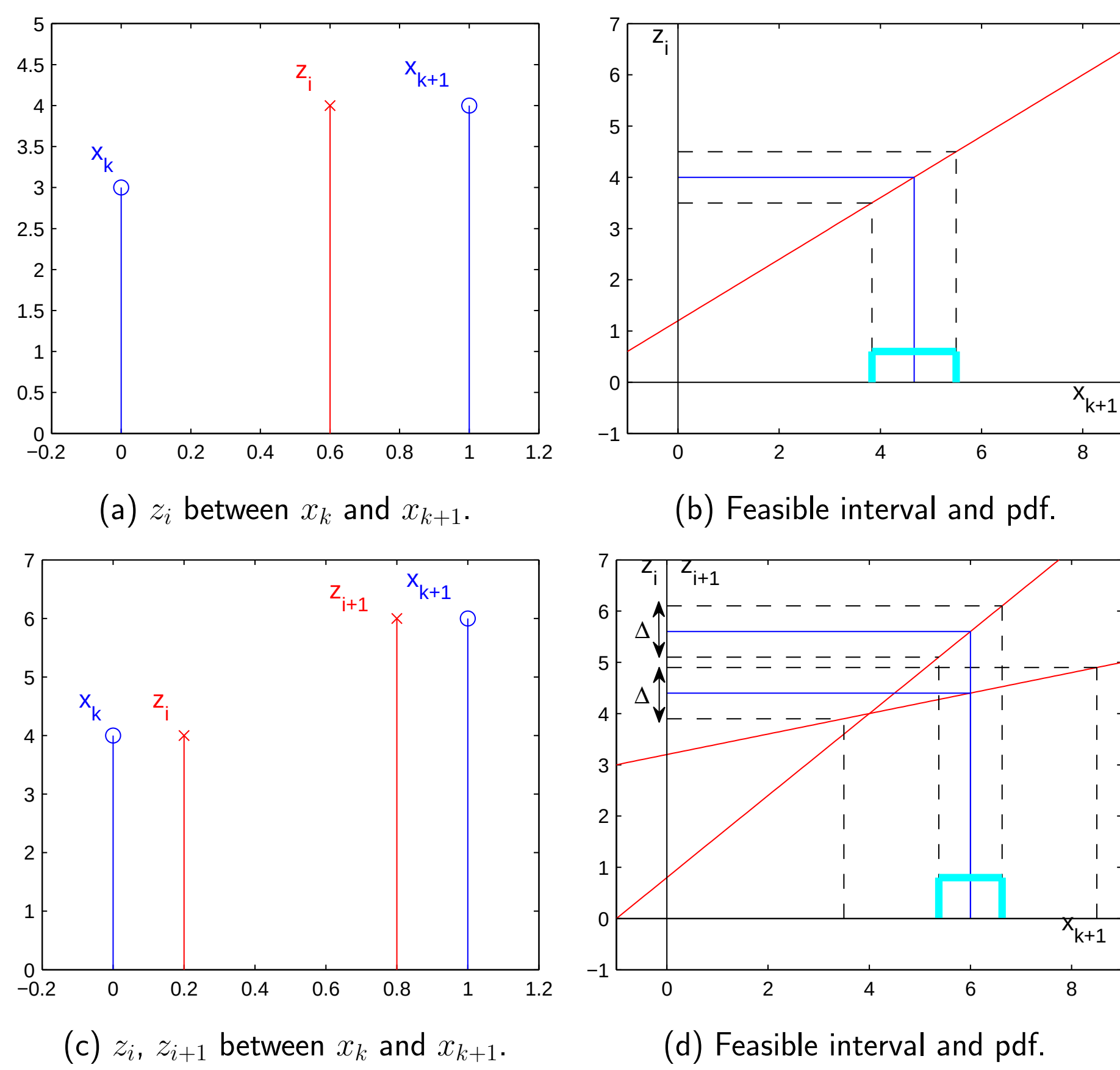
- If z_i is the only sample between two original ones:

$$f_{Z_i|X_k, X_{k+1}}(z_i|x_k, x_{k+1}) = \Pi\left(\frac{a_i x_k + b_i x_{k+1} - z_i}{\Delta}\right).$$

- If z_i is one of several resampled values between two original samples:

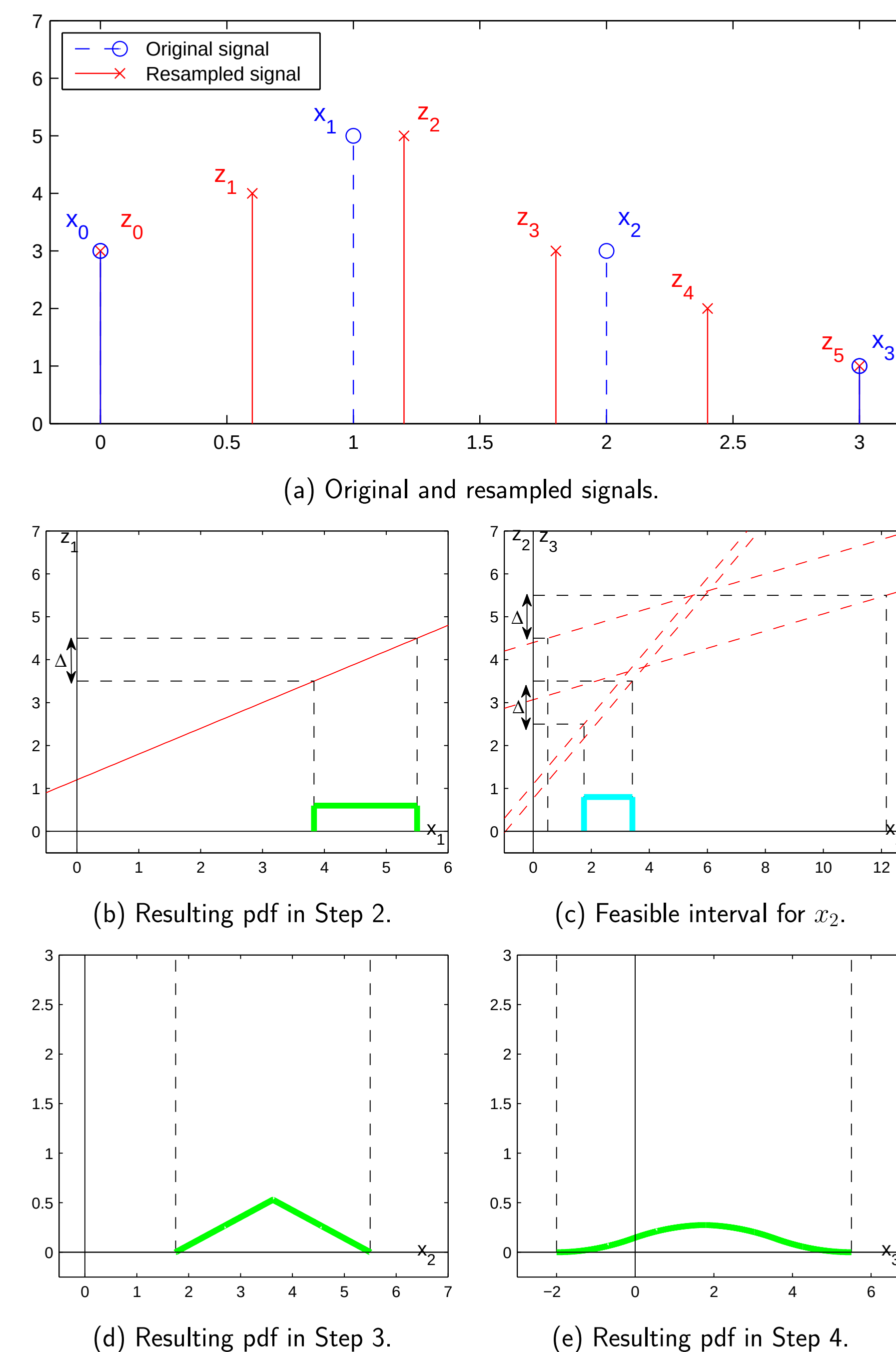
$$f_{\mathbf{Z}_i|X_k, X_{k+1}}(\mathbf{z}_i|x_k, x_{k+1}) = \prod_m \Pi\left(\frac{a_m x_k + b_m x_{k+1} - z_m}{\Delta}\right).$$

Note: $\Pi(t)$ denotes a rectangular pulse that is 1 if $t \in [-\frac{1}{2}, \frac{1}{2}]$ and 0 otherwise.



Method Description with an Example ($\xi = 5/3$)

- First sample z_0 is visible, so $z_0 = x_0$.
- From z_1 and its relation with x_0 , a feasible interval and the corresponding pdf are obtained for x_1 .
- From the range of x_1 and its relation with z_2 and z_3 , a feasible range is obtained for x_2 by intersecting two intervals and then the resulting pdf is computed.
- From the range of x_2 and its relation with z_4 , a feasible interval and pdf are obtained for x_3 .
- After processing these L samples, the next sample is visible (i.e., $z_5 = x_3$), thus we can check if z_5 falls in the obtained feasible range of x_3 .

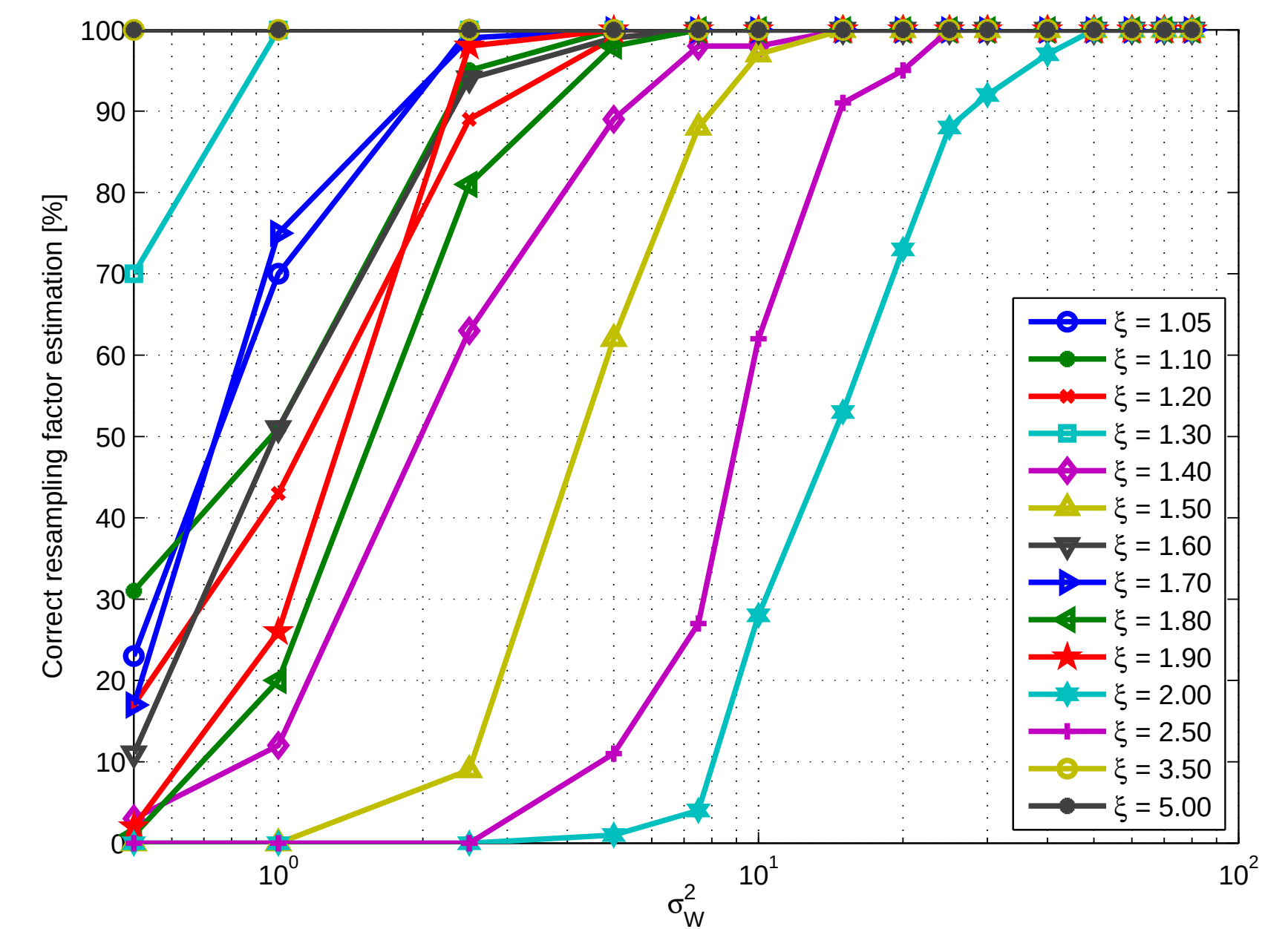


Performance analysis with synthetic signals

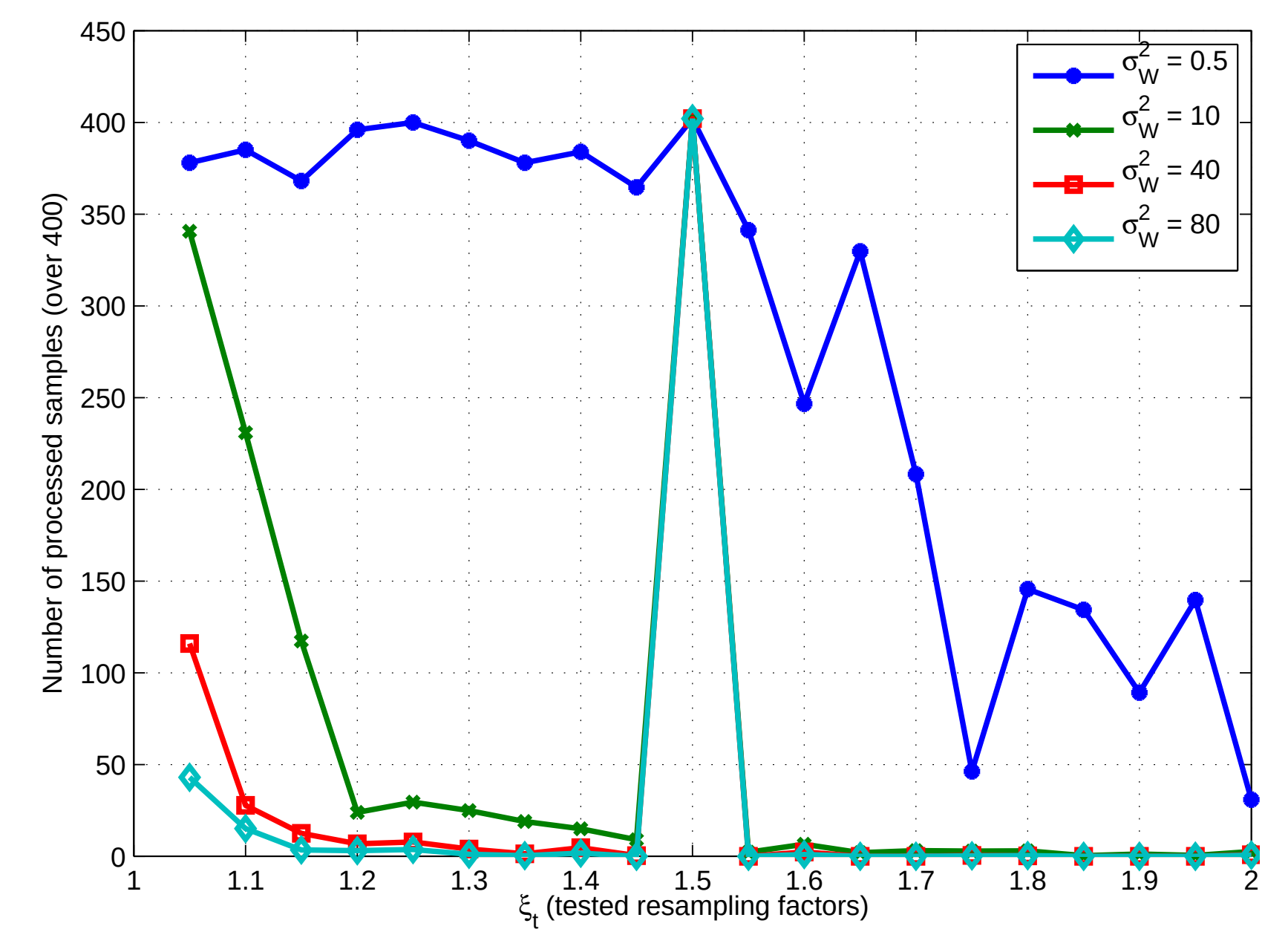
First-order autoregressive process, AR(1):

$$u(n) = w(n) + \rho u(n-1).$$

- $w(n)$ is Gaussian with zero mean and variance σ_W^2 .
- $x(n) = Q_{\Delta}(u(n))$ with $\Delta = 1$.
- $\rho = 0.95$.



(a) Correct resampling factor estimation rate as a function of σ_W^2 .

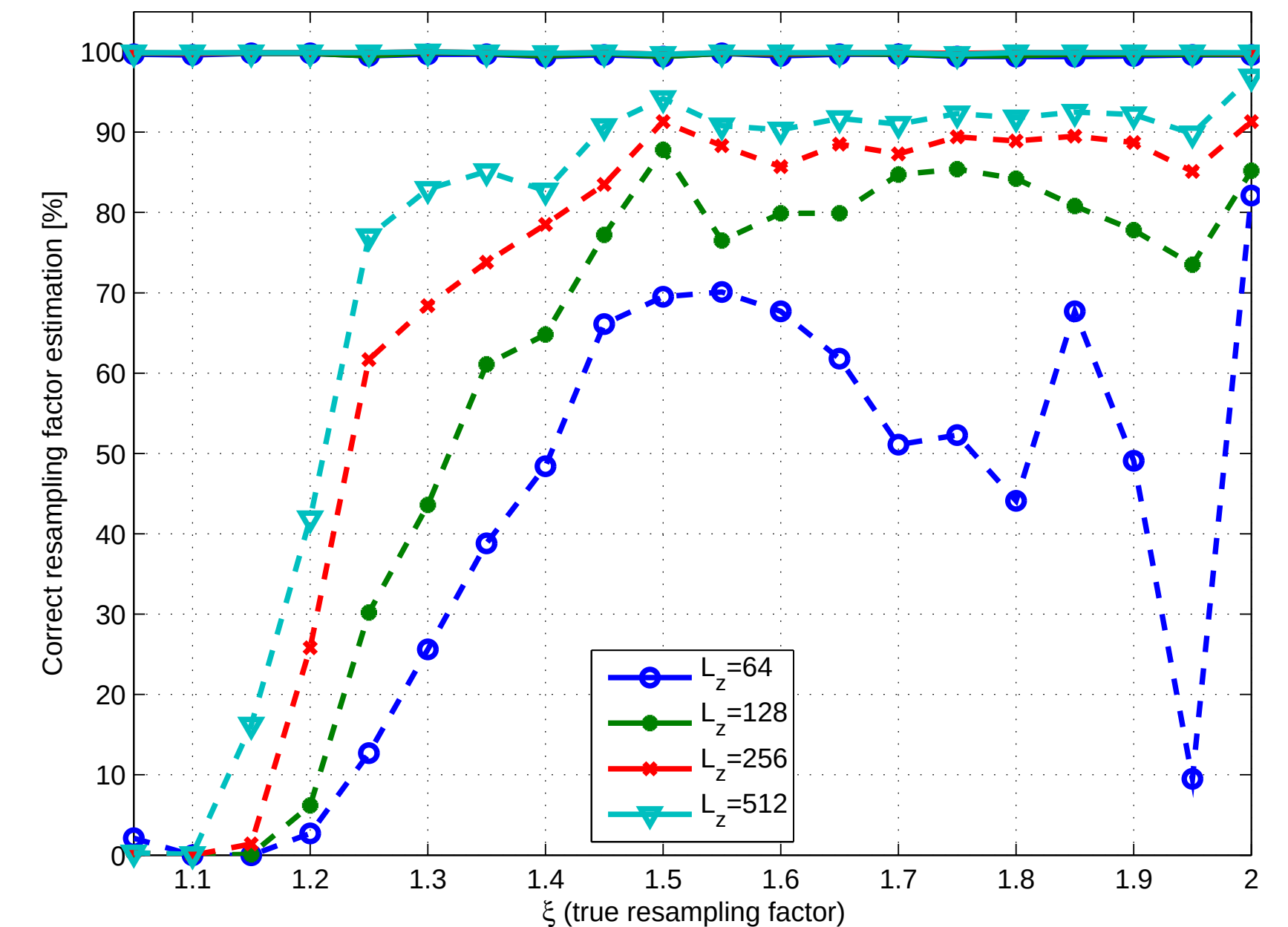


(b) Number of processed samples for different values of σ_W^2 , as a function of ξ_t , for $\xi = \frac{3}{2}$.

Comparison with Popescu and Farid's Method

Dataset for experimental validation:

- "Music Genres" audio database [2].
- 1000 uncompressed audio files.
- 10 different music styles (blues, country, jazz, pop, ...).



Comparison of the proposed MLE (solid lines) versus the method in [1] (dashed lines).

Future Work

- Generalize the idea to any interpolation filter.
- Extend this work to the 2-D case for testing images.
- Trace links between this work and set membership algorithms.
- Study the case with noisy observations and with $\xi < 1$.

References

- [1] A. Popescu and H. Farid, "Exposing digital forgeries by detecting traces of resampling," in *IEEE Transactions on Signal Processing*, vol. 53, no. 2, pp. 758-767, Feb. 2005.
- [2] <http://opihi.cs.uvic.ca/sound/genres.tar.gz>