Correlation-Based Processing for Nearly Optimal Morse Code Reception

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Create sample stream of simulating on/off keying similar to Morse Code.

$N := 2048$

$kk := 0 .. N-1$

Assume 50 WPM, 5 char/word, 5 baud per char, and 64 samples per baud= 1333 Hz sampling rate. So, set to 44 kHz/32 = 1375 Hz

$ds_{kk} := if(kk < 32, 0, 1)$

$ds_{kk} := if(kk > 64, 0, ds_{kk})$

$Fs := 1375$

$ds_{kk} := if(kk > 128, 1, ds_{kk})$

$ds_{kk} := if(kk > 160, 0, ds_{kk})$

$ds_{kk} := if(kk > 192, 1, ds_{kk})$

$ds_{kk} := if(kk > 256, 0, ds_{kk})$

$ds_{kk} := if(kk > 320, 1, ds_{kk})$

$F_o := 126$

$ds_{kk} := if(kk > 352, 0, ds_{kk})$

$dt := \frac{1}{1375}$ $A := 4.18$

$ds_{kk} := if(kk > 480, 1, ds_{kk})$

$ds_{kk} := if(kk > 512, 0, ds_{kk})$

$SNR := \frac{A^2}{2} \cdot \frac{1}{3 \cdot 0.25}$

$ds_{kk} := if(kk > 800, 1, ds_{kk})$

SNR= $10 \cdot log(SNR) = 10.663$ dB

Create random I & Q signal sample streams including simple uniformly distributed noise.

$I_{kk} := (-1.5 + \mathrm{rnd}(1) + \mathrm{rnd}(1) + \mathrm{rnd}(1)) + A \cdot ds_{kk} \cdot \cos(2 \cdot \pi \cdot F_o \cdot dt \cdot kk)$

$Q_{kk} := (-1.5 + \mathrm{rnd}(1) + \mathrm{rnd}(1) + \mathrm{rnd}(1)) + A \cdot ds_{kk} \cdot \sin(2 \cdot \pi \cdot F_o \cdot dt \cdot kk)$

$lag := 4$

Form complex autocorrelation function using a sample lag of "lag"

$ii := 0 .. N - 1 - lag$ $jx := \sqrt{-1}$ $\alpha := 0.93$

$\rho_{kk} := 0$

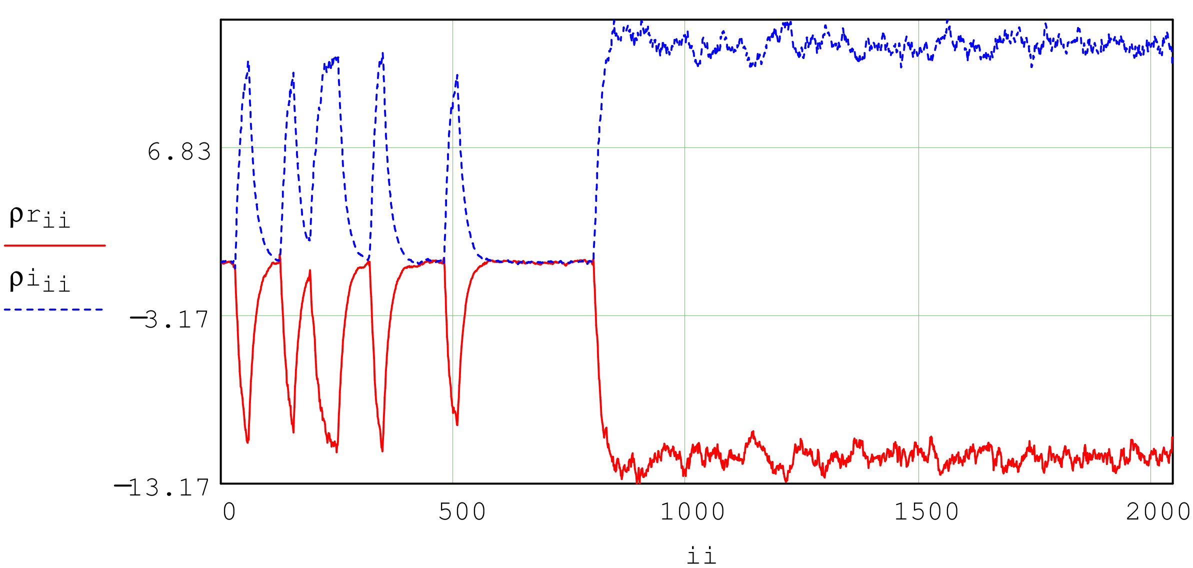
$\rho_{ii} := (I_{ii} - jx \cdot Q_{ii}) \cdot (I_{ii+lag} + jx \cdot Q_{ii+lag})$

$\rho r_0 := 0$ $\rho i_0 := 0$ $\rho_{N-2-lag} := 0$

$\rho r_{ii+1} := \alpha \cdot \rho r_{ii} + (1 - \alpha) \cdot \mathrm{Re}(\rho_{ii+1})$

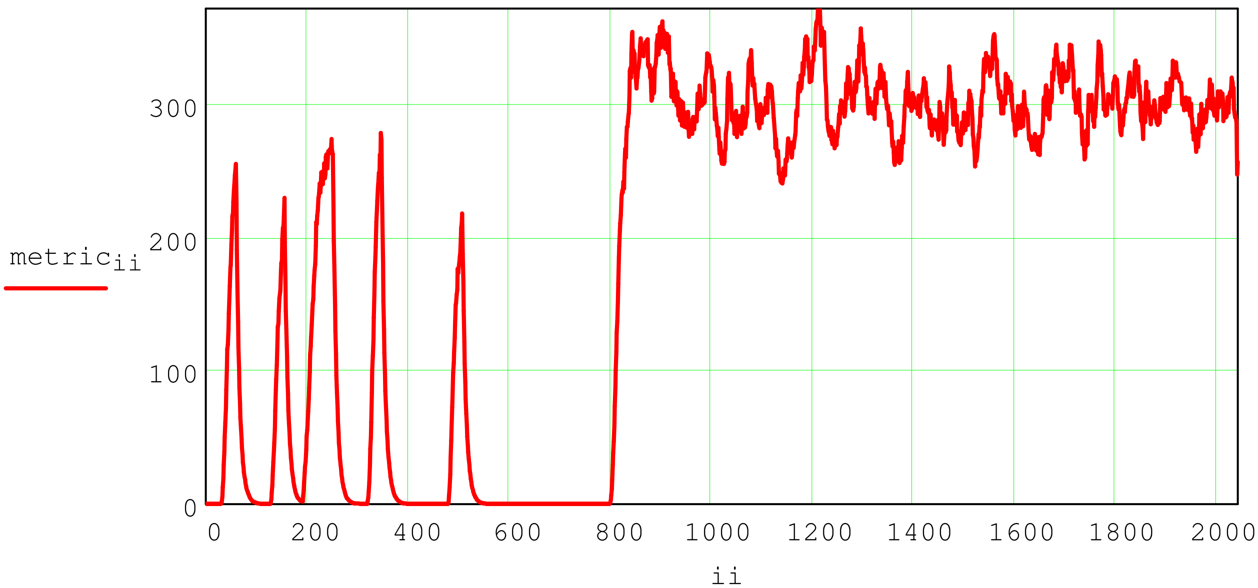
$\rho i_{ii+1} := \alpha \cdot \rho i_{ii} + (1 - \alpha) \cdot \mathrm{Im}(\rho_{ii+1})$

Real and Imaginary Part of Complex Autocorrelation Function



$$metric_{ii} := (\rho r_{ii})^2 + (\rho i_{ii})^2$$

Detection Metric Versus Time Index

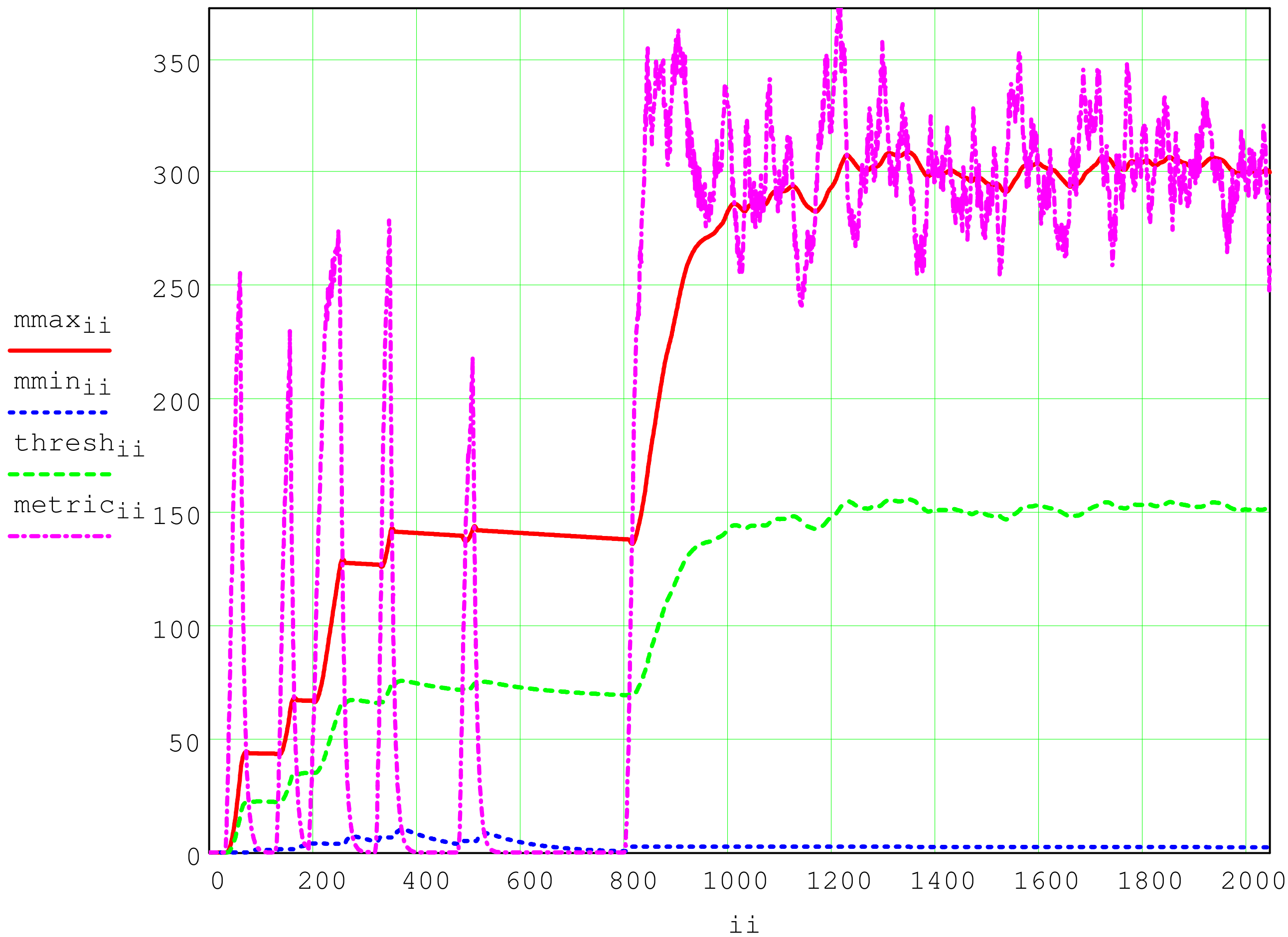


$thresh_0 := 0 \qquad mmax_0 := 0 \qquad mmin_0 := 0$

$\beta := 0.99 \qquad d := 0.9999 \qquad \gamma := 1 - \beta$

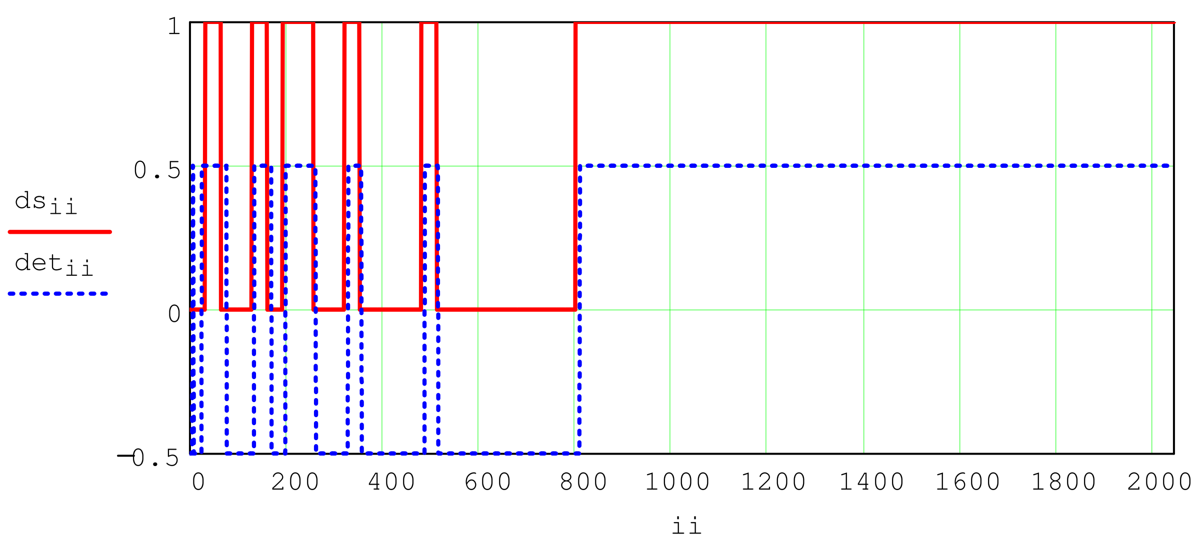
$$\begin{pmatrix} mmax_{ii+1} \\ mmin_{ii+1} \\ thresh_{ii+1} \end{pmatrix} := \begin{bmatrix} if\left(\left|metric_{ii}\right| > thresh_{ii}, \beta \cdot mmax_{ii} + \gamma \cdot metric_{ii}, mmax_{ii} \cdot d\right) \\ if\left(\left|metric_{ii}\right| < thresh_{ii}, \beta \cdot mmin_{ii} + \gamma \cdot metric_{ii}, mmin_{ii} \cdot d\right) \\ 0.5 \cdot (mmax_{ii} + mmin_{ii}) + 0.01 \end{bmatrix}$$

If mmin is not close to zero, smoothing parameters need adjustment

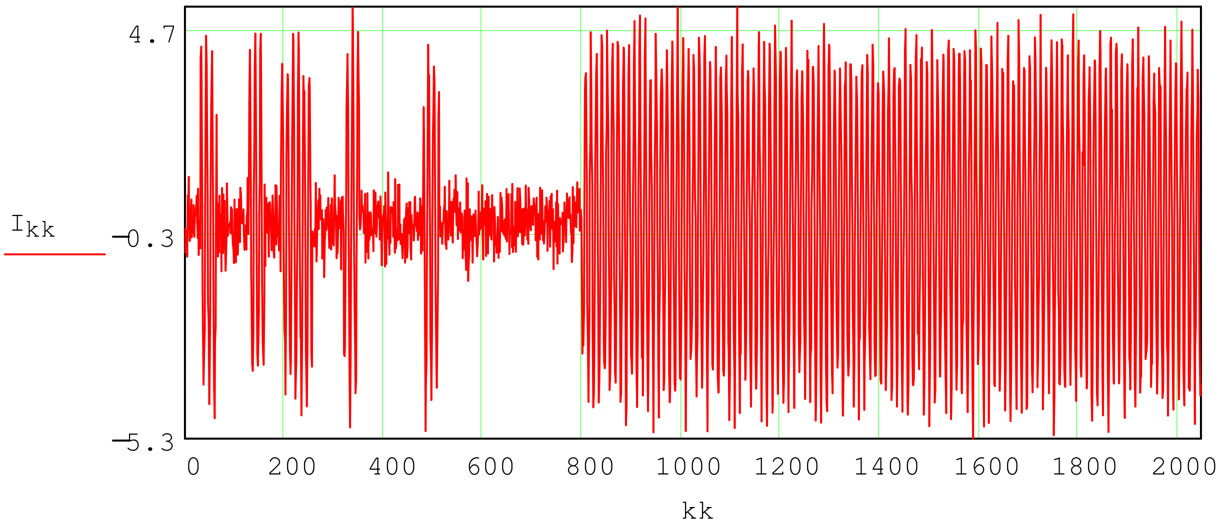


$det_{ii} := if(metric_{ii} > thresh_{ii}, 0.5, -0.5)$

Detector Output Overlaid with Noise-Free Input



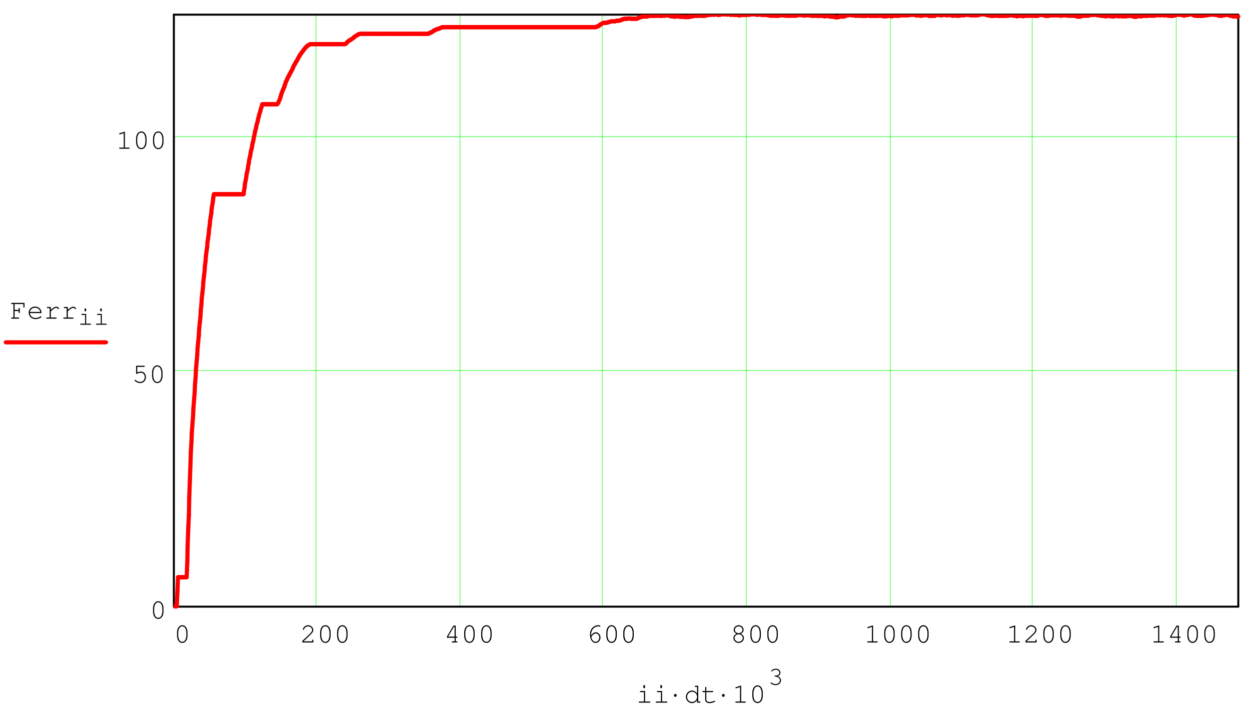
Use hysteresis in PC algorithm to drop out short spikes



$Ferr_0 := 0$

$$Ferr_{ii+1} := \text{if}\left(metric_{ii} > thresh_{ii},\ 0.98 \cdot Ferr_{ii} + \frac{0.02}{2 \cdot \pi \cdot dt \cdot lag} \cdot angle\left(\rho r_{ii}, \rho i_{ii}\right.\right.$$

Frequency Error Estimate Versus Time



$Ferr_{1800} = 125.859$

Time, msec

$\Big)\, ,\, Ferr_{ii}\Bigg)$