Lecture 5. Image data fusion (4 hours)

5.1. Mathematical models of multi-component imaging systems

5.2. Principles of MSE – optimal linear scalar filtering methods for image data fusion

$$\left\{\hat{a}_k^{(m)}\right\} = \underset{\mathrm{R}\{b_k\}=\{\hat{a}_k\}}{\arg\min}\left\{ \mathrm{AV}_{\Omega_A}\mathrm{AV}_{\Omega_N}\left(\sum_{k=0}^{N-1}\left|a_k^{(m)} - \hat{a}_k^{(m)}\right|^2\right)\right\},\ m=1,\dots,M$$ (the number of image modalities)

"Scalar" filtering in transform domain: $\hat{\mathbf{A}}^{(m)} = \mathbf{T}^{-1}\left(\sum_{l=1}^{M}\cdot \mathbf{H}_d^{(m,l)}\cdot \mathbf{T}\cdot \mathbf{B}^{(l)}\right) \Rightarrow$

$\hat{\alpha}_r^m = \sum_{l=1}^{M}\eta_r^{(m,l)}\beta_r^{(l)}$, where $\left\{\hat{\alpha}_r^{(m)}\right\} = \mathbf{T}\cdot\hat{\mathbf{A}}^{(m)}$ and $\left\{\beta_r^{(l)}\right\} = \mathbf{T}\cdot\mathbf{B}^{(l)}$

$$\Rightarrow \eta_{r,opt}^{(m,l)} = \underset{\{\eta_r\}}{\arg\min}\left\{\mathrm{AV}_{\Omega_A}\mathrm{AV}_{\Omega_N}\left(\sum_{r=0}^{N-1}\left|\alpha_r^{(m)} - \sum_{l=1}^{M}\eta_r^{(m,l)}\beta_r^{(l)}\right|^2\right)\right\}$$

5.3. Multi component image denoising and deblurring:

$$\left\{\beta_r^{(m)} = \lambda_r^{(m)}\alpha_r^{(m)} + \nu_r^{(m)}\right\} \Rightarrow$$

$$\eta_r^{(m,l)} = \frac{1}{\lambda_r^{(l)}}\frac{AV_{\Omega_A}\left(\alpha_r^{(m)}\alpha_r^{(l)}\right)}{AV_{\Omega_A}\left(\left|\alpha_r^{(l)}\right|^2\right)}\frac{SNR_r^{(l)}}{1+\sum_{m=1}^{M}SNR_r^{(m)}},\ \text{where}\ \left\{SNR_r^{(m)} = \frac{\left|\lambda_r^{(m)}\right|^2\mathrm{AV}_{\Omega_A}\left(\left|\alpha_r^{(m)}\right|^2\right)}{\mathrm{AV}_{\Omega_n}\left(\left|\nu_r^{(m)}\right|^2\right)}\right\}$$

5.4. Correlational accumulation for image denoising, deblurring and "super-resolution"

Image averaging: $\hat{a}_k = \sum_{m=1}^{M} b_k^{(m)}/\left(\sigma_n^{(m)}\right)^2 \Big/ \sum_{m=1}^{M} 1/\left(\sigma_n^{(m)}\right)^2$

Image mutual alignment: $\dfrac{AV_{\Omega_A}\left(\alpha_r^{(m)}\alpha_r^{(l)}\right)}{AV_{\Omega_A}\left(\left|\alpha_r^{(l)}\right|^2\right)} = \exp\left(i2\pi\dfrac{u^{(m,l)}r}{N}\right)$, where $u^{(m,l)}$ is mutual misalignment

Image alignment and averaging $\hat{\alpha}_r^{(m)} = \dfrac{\sum_{l=1}^{M}\exp\left[i2\pi\dfrac{u^{(m,l)}}{N}r\right]\beta_r^{(l)}/\sigma_n^{(l)}}{\sum_{l=1}^{M}1/\sigma_n^{(l)}}$

Expected performance of the correlational accumulation: denoising, deblurring, super-resolution.
Image super resolution from multiple frames: potentials and limits

5.5. Case study: Correlational averaging of electron micrographs.

Misalignment errors: normal and anomalous. Normal misalignment errors limit additive noise variance reduction factor to $M\cdot\left(1-P_{an.err}\right)$ and cause restored signal blur with PSF determined by variance of normal errors. Anomalous misalignment errors cause a spurious signal resulted from accumulation of noise realizations that exhibited high correlation with the signal template.

Iterative restoration algorithm: one of the noisy realizations is used as an initial template which is then replaced, at each new iteration, by the estimated signal obtained on the previous iteration.

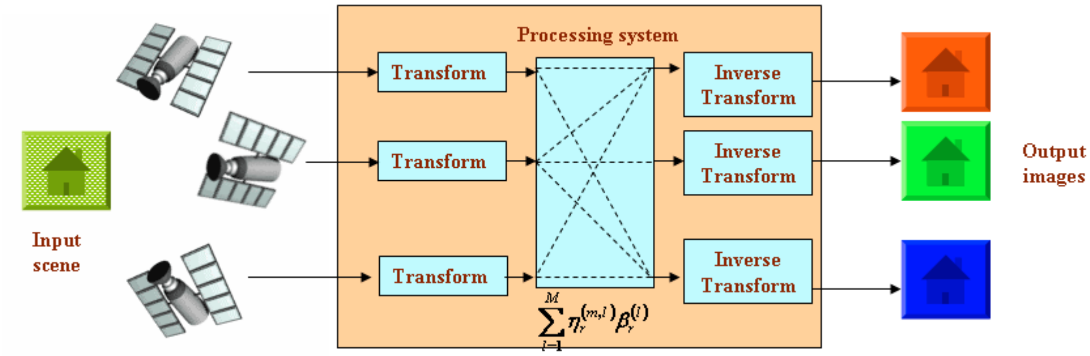
Two-channel algorithm: correlational signal accumulation is supplemented with accumulation of the signal power Fourier spectra. The former is then used to compute phase component of the restored signal Fourier spectrum; the latter provides estimation of the magnitude of the spectrum. This allows to reduce signal blur due to misalignment errors.

Additional reading:

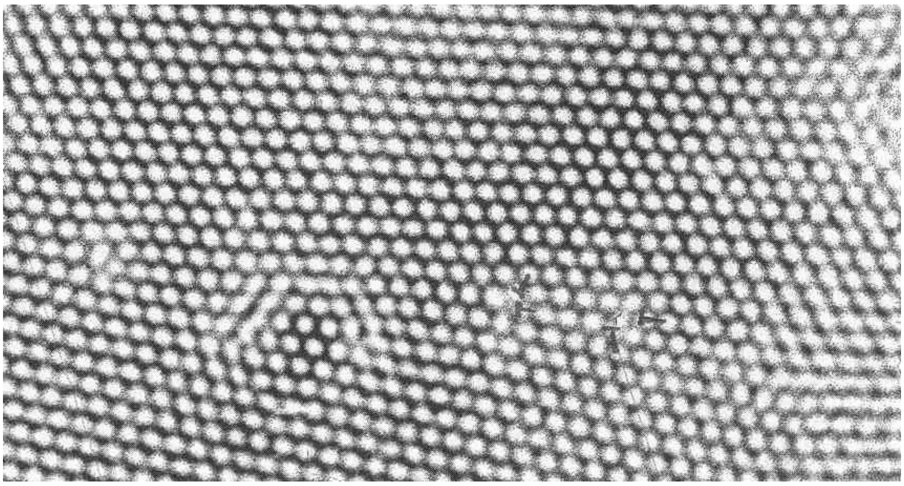
L.P.Yaroslavsky, H.J. Caulfield, Deconvolution of Multiple Images of the same object, Appl. Opt., Vol. 33, No 11, p. 2157-21

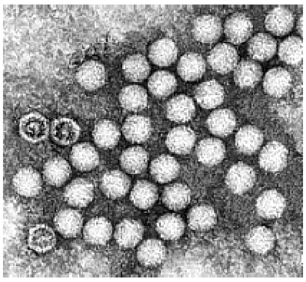
L. Yaroslavsky, M. Eden, Correlational Accumulation as a Method for Signal Restoration, Signal Processing, 39 (1994) p. 89-106

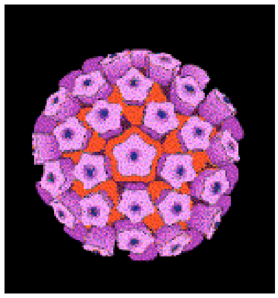
The principle of image data linear fusion



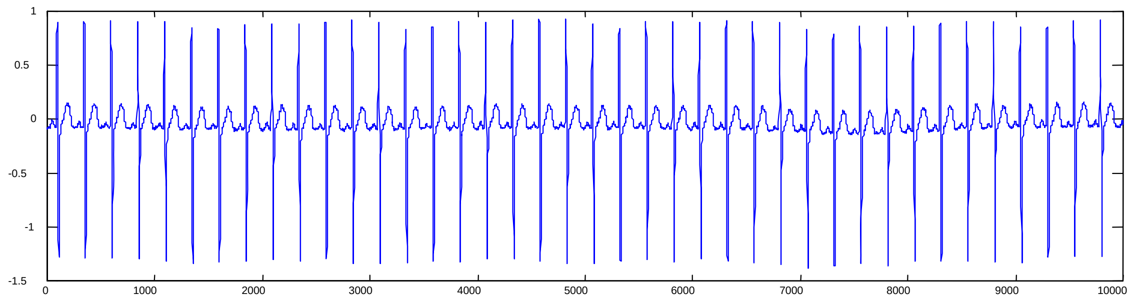
Correlational averaging in processing of electron micrographs



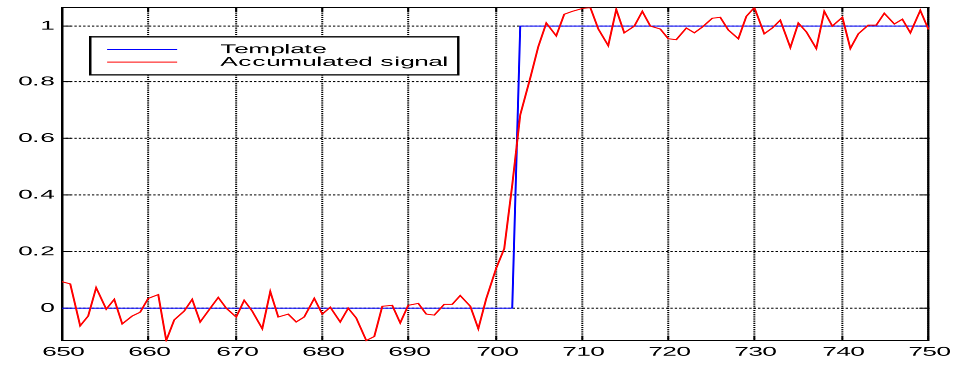




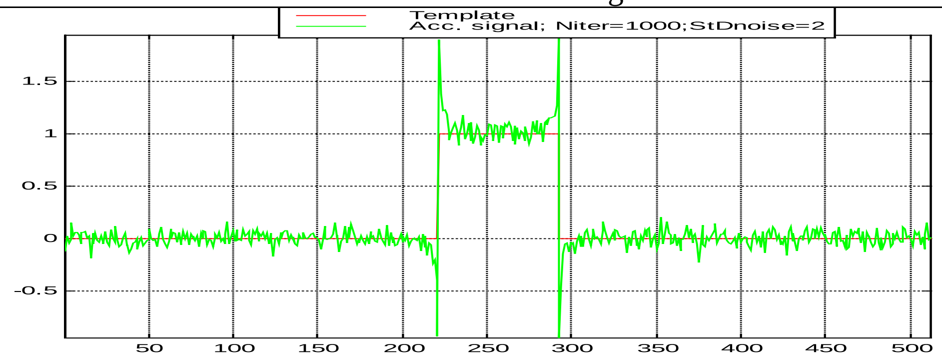
Examples of electron micrographs of virus particles and 3D reconstruction of the virus



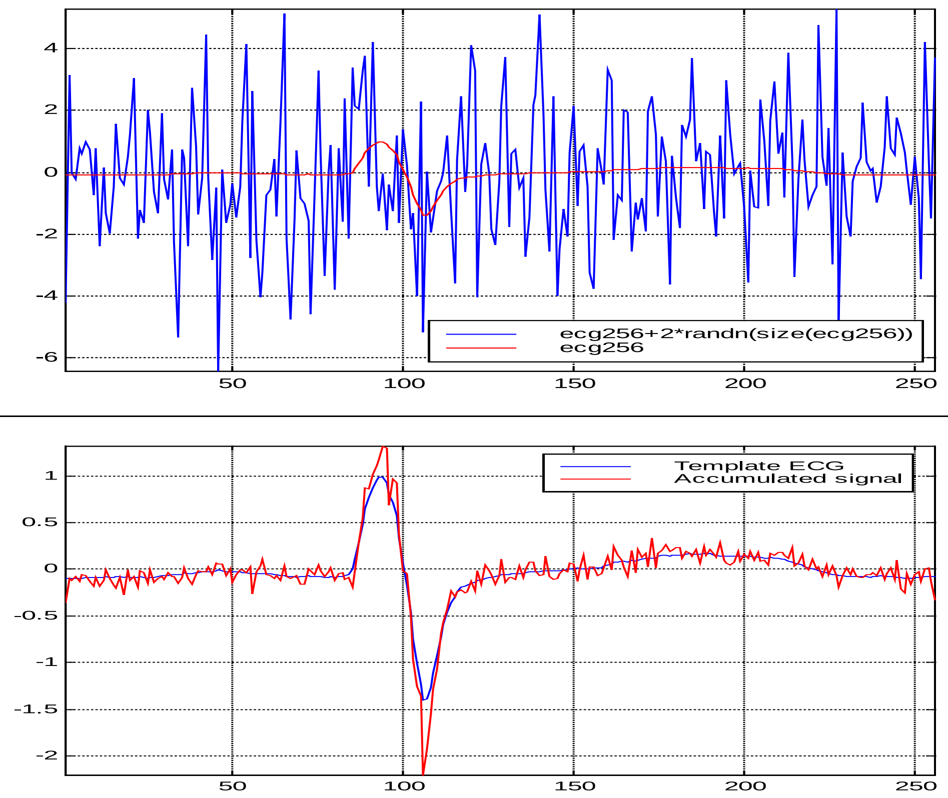
A typical electrocardiogram signal



Correlational accumulation: signal blur.



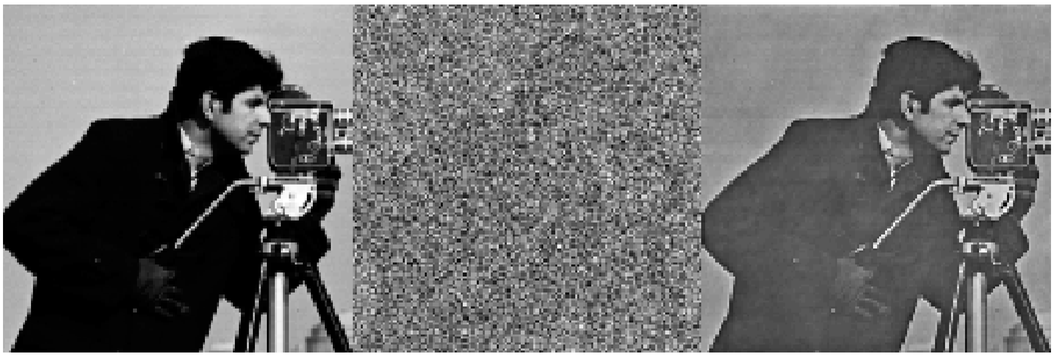
Correlational accumulation: artifacts due to anomalous alignment errors



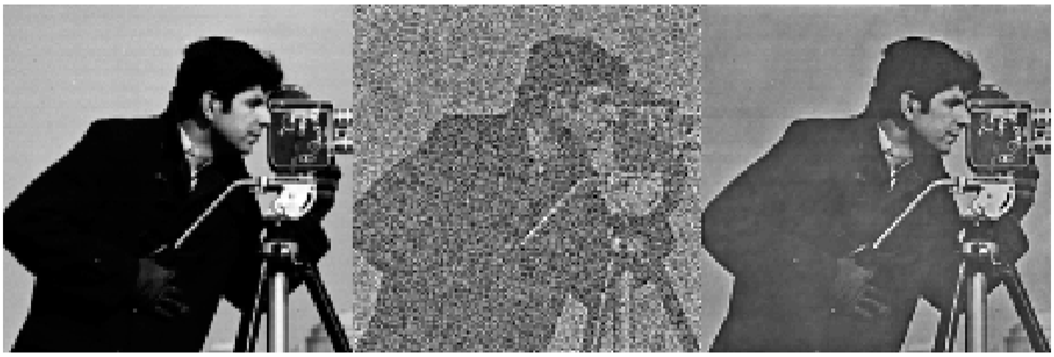
Correlational accumulation of a piece of ECG: 1000 iterations

Correlational accumulation: accumulation of template-correlated noise

Correlational accumulation; Nit=100.
Template, accumulated image and 0.75-whitened template

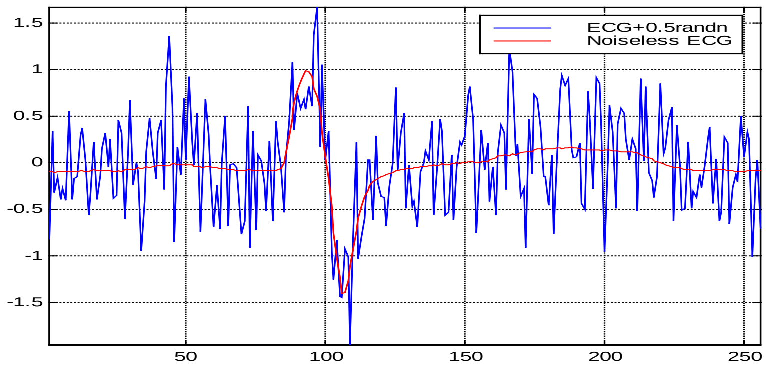


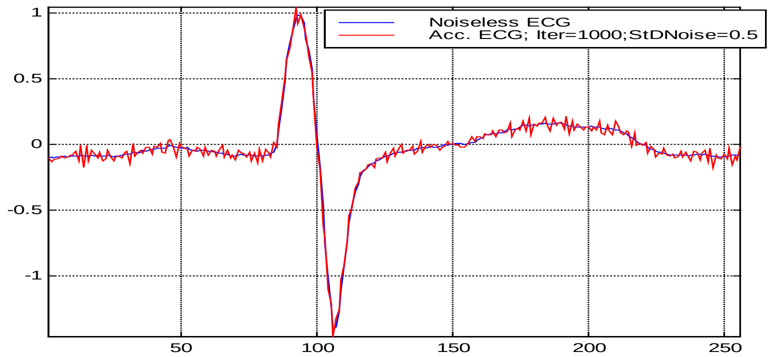
Correlational accumulation; Nit=1000.
Template, accumulated image and 0.75-whitened template

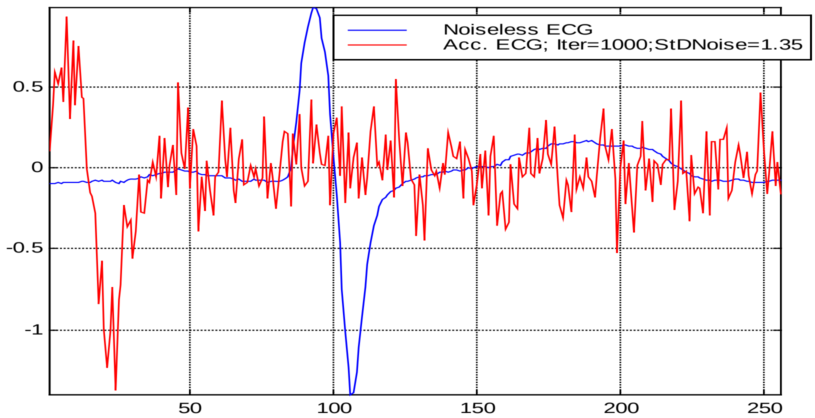


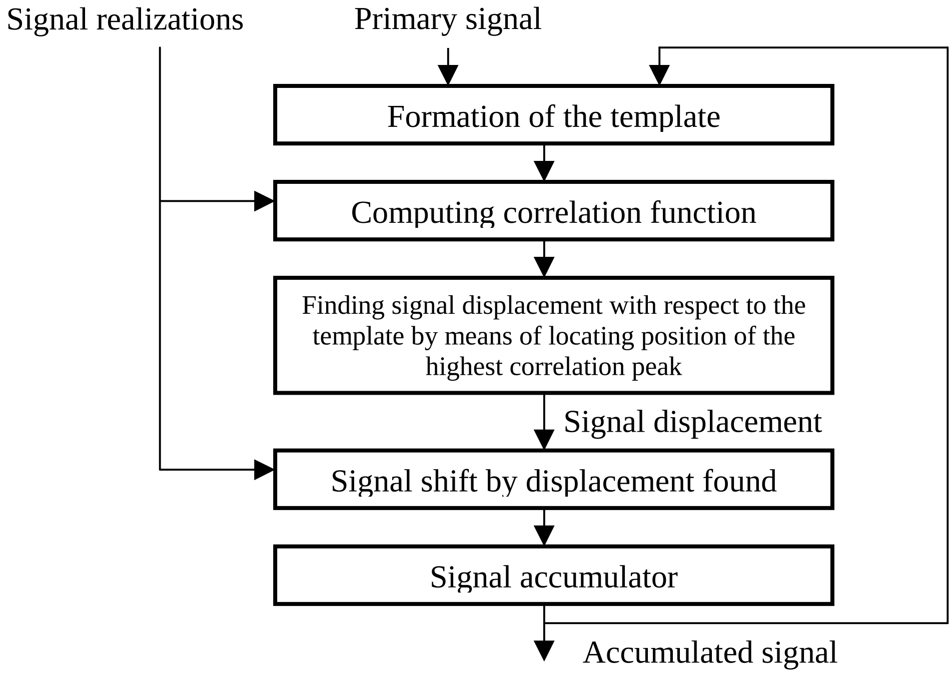
Correlational accumulation; Nit=10000.
Template, accumulated image and 0.75-whitened template

Iterative correlational accumulation: threshold effect

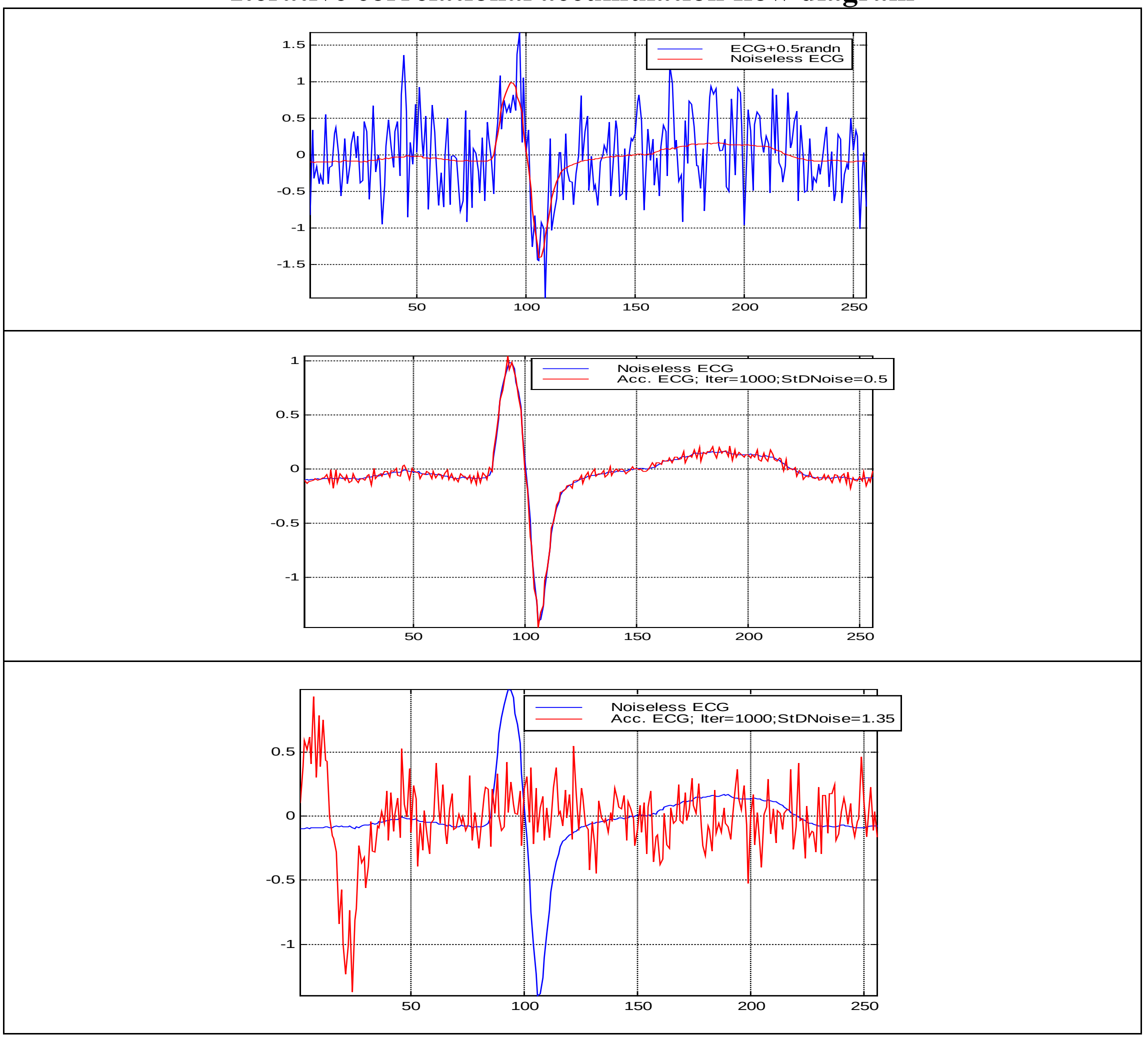




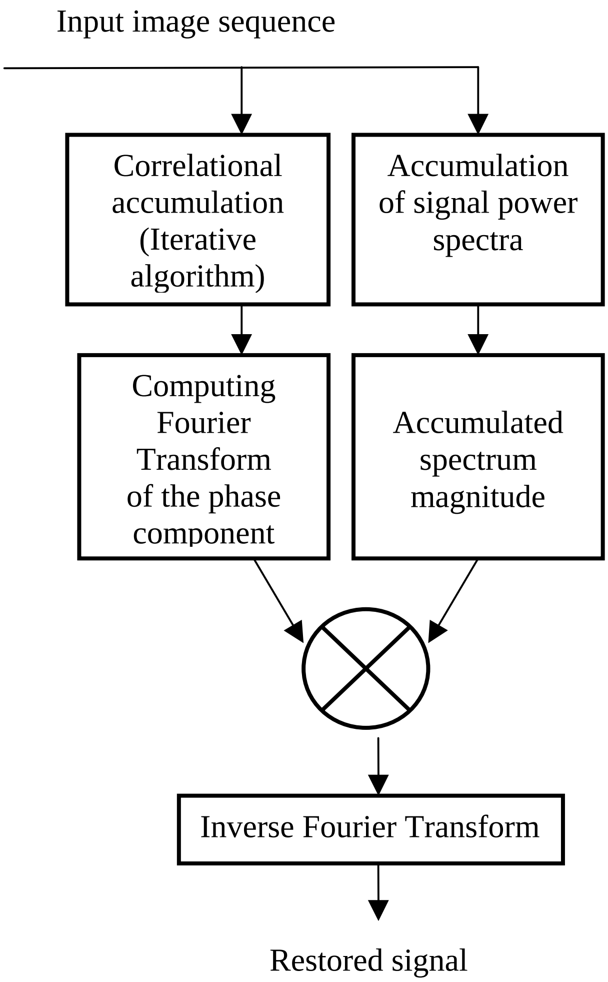


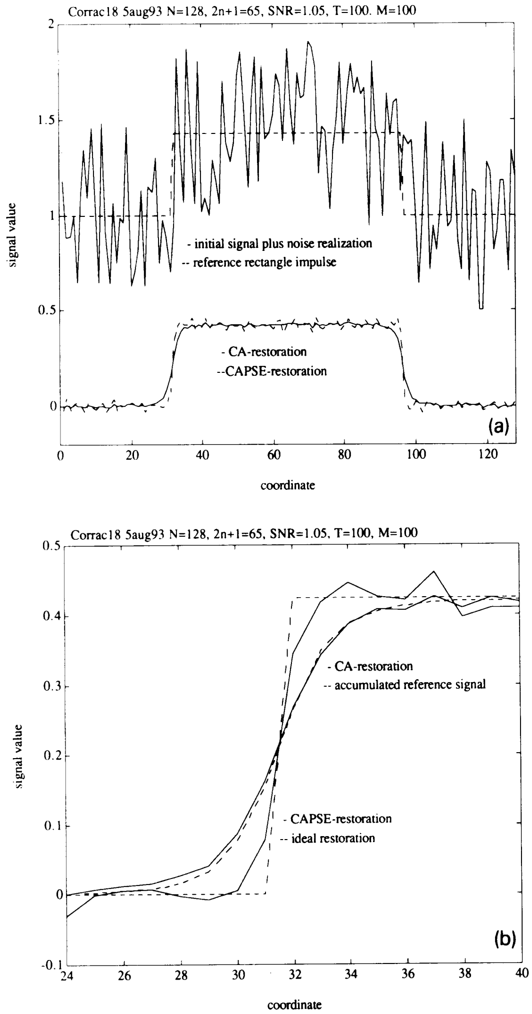


Iterative correlational accumulation flow diagram



Iterative correlational accumulation: threshold effect





Comparison of the restoration quality for CA- and CAPSE-restoration: (a) entire signals, (b) fragments of the signals around the signal edge.

A two channel correlational accumulation with phase spectrum estimation (CAPSE) algorithm

Lecture 4. Image data fusion (4 hours)

5.6. "Local" algorithms

$$\left\{\hat{a}_k^{(m)}\right\} = \underset{\{b_{\bar{k}}\} \Rightarrow \{\hat{a}_k\}}{\arg\min} \left\{ \mathbf{AV}_{\Omega_A} \mathbf{AV}_{\Omega_N} \left(\sum_{\bar{k}=0}^{N_W-1} \left| a_{\bar{k}}^{(m)} - \hat{a}_{\bar{k}}^{(m)} \right|^2 \right) \right\}, \left\{\bar{k}\right\} \in \mathbf{Spatial/TemporalWindowAroundPixel}\ k$$

5.7. 3-D spatial-temporal video data fusion

Denoising and deblurring videos acquired by thermal cameras

5.8. Case study: stabilization and super-resolution of turbulent videos.

Image "elastic" registration: obtaining local misalignment parameters

Optical flow" methods: $\left[\Delta\hat{x}_{SW}, \Delta\hat{y}_{SW}\right] = \arg\min \sum_{x,y \in SpatialWindow} \left| I_{(x,y)} - \hat{I}_{x+\Delta\hat{x}, y+\Delta\hat{y}} \right|^2 \Rightarrow$

Equation for finding $\left[\Delta\hat{x}_{SW}, \Delta\hat{y}_{SW}\right]$: $\frac{\partial E}{\partial \vec{\Delta}} = \sum_{x,y,\in SW} \left\{ -2 \cdot \left[\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y} \right] \cdot \left(I_{x,y} - \left[\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y} \right]^T \cdot [\Delta x, \Delta y] \right) \right\} = 0$

Local correlational methods: $(\Delta\hat{x}_0, \Delta\hat{y}_0) = [x, y] - \arg\max(I_{x',y' \in SpatialWindow} \otimes \hat{I})_{x,y}$

Stabilization of video acquired through turbulent atmosphere

5.9. Multi-modality imaging and inter-channel data fusion

http://www.eng.tau.ac.il/~yaro/lectnotes/pdf/ImageDataFusion.pdf