

L. Yaroslavsky. Course 5107212. Selected Topics in Image Processing, Graphics and Computer Vision
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

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

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

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

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

5.3. Multi component image denoising and deblurring:

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

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

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

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

Image mutual alignment: $\frac{\text{AV}_{\Omega_A} (\alpha_r^{(m)} \alpha_r^{(l)})}{\text{AV}_{\Omega_A} (|\alpha_r^{(l)}|^2)} = \exp \left(i 2\pi \frac{u^{(m,l)} r}{N} \right)$, where $u^{(m,l)}$ is mutual misalignment

Image alignment and averaging $\hat{\alpha}_r^{(m)} = \frac{\sum_{l=1}^M \exp \left[i 2\pi \frac{u^{(m,l)} r}{N} \right] \beta_r^{(l)} / \sigma_n^{(l)}}{\sum_{l=1}^M 1 / \sigma_n^{(l)}}$

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 $M \cdot (1 - P_{an,err})$ 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.

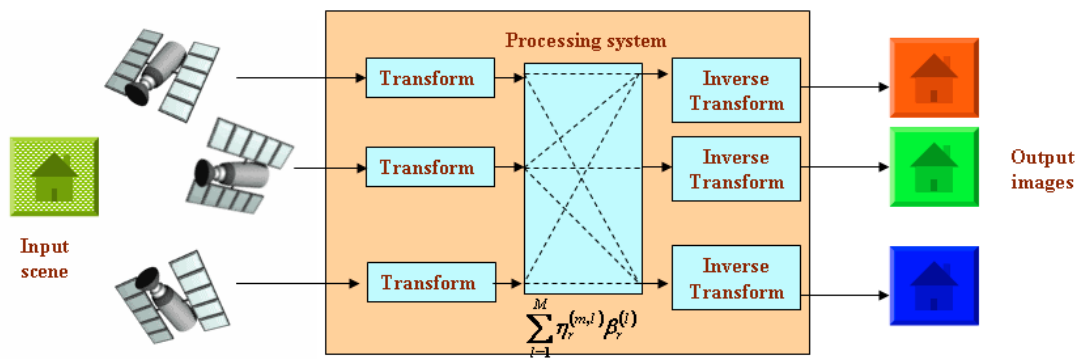
Two-channel algorithm: correlational signal accumulation is supplemented with accumulation of the signal power Fourier spectra. The former is then used to compute phase component of the restored signal Fourier spectrum; the latter provides estimation of the magnitude of the spectrum. This allows to reduce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

Additional reading:

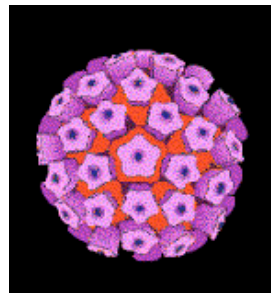
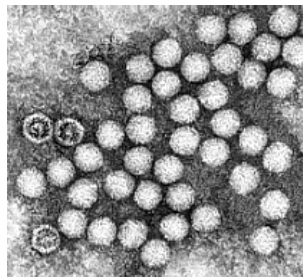
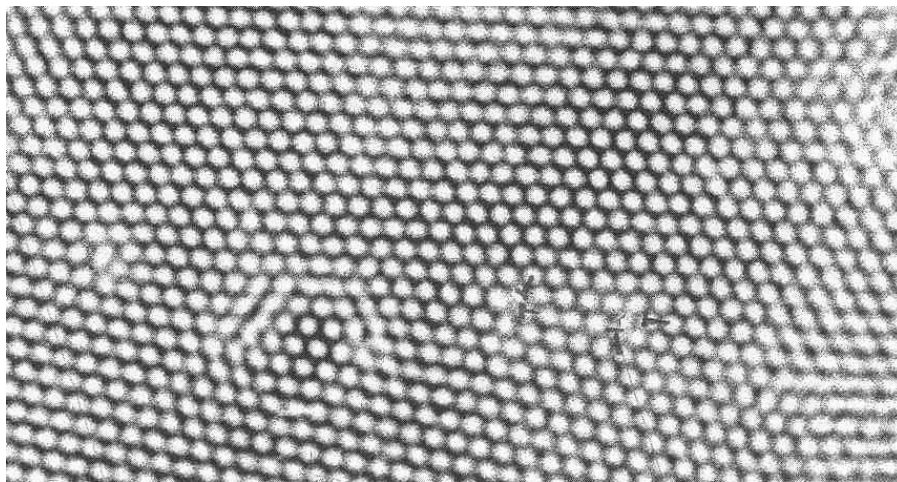
L.P.Yaroslavsky, H.J. Caulfield, Deconvolution of Multiple Images of the same object, Appl. Opt., Vol. 33, No 11, p. 2157-21

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

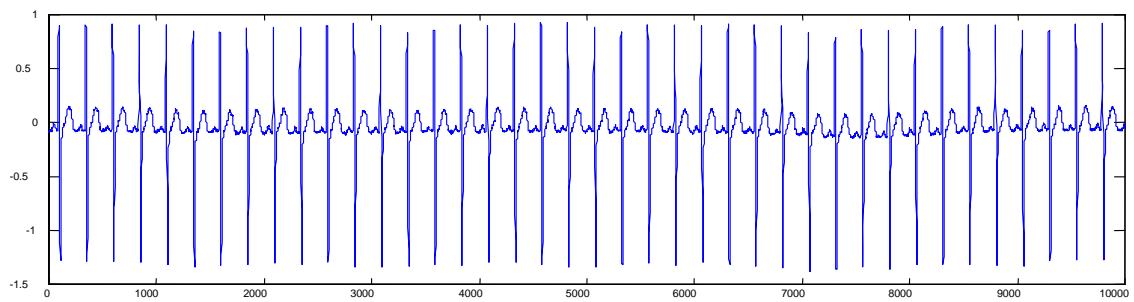
The principle of image data linear fusion



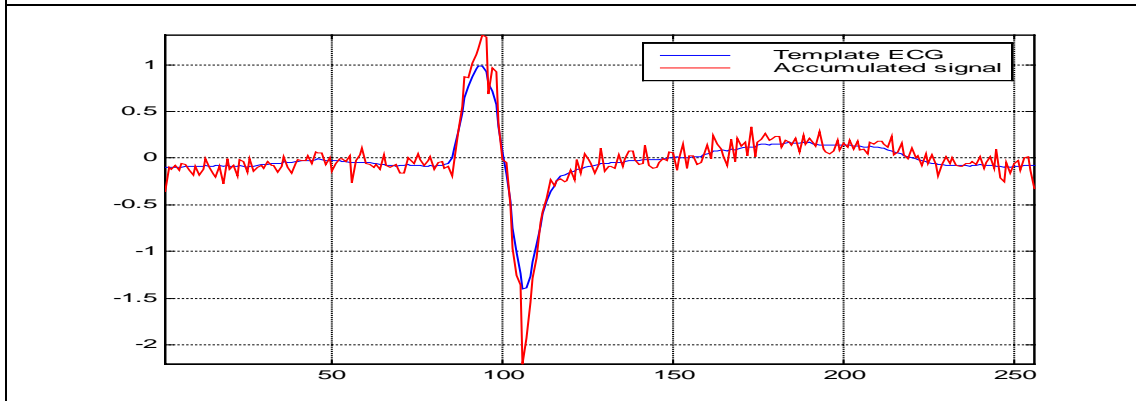
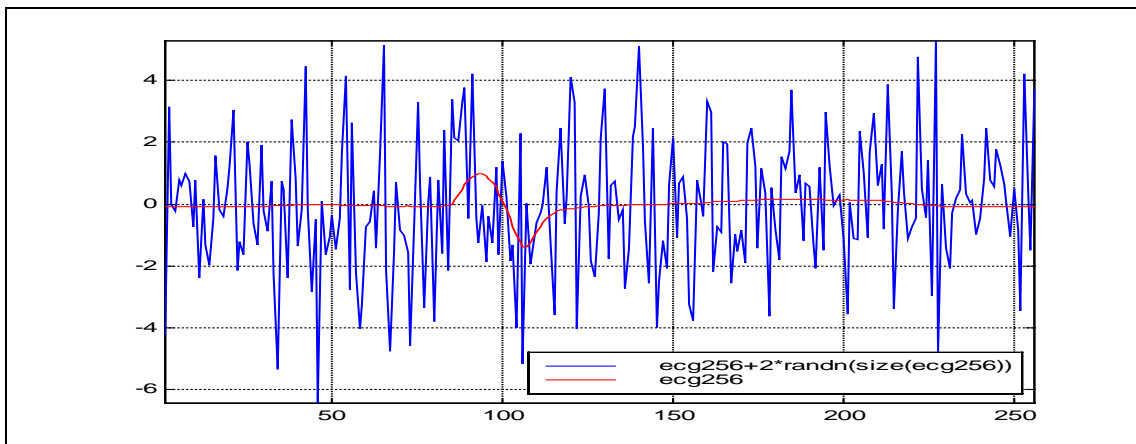
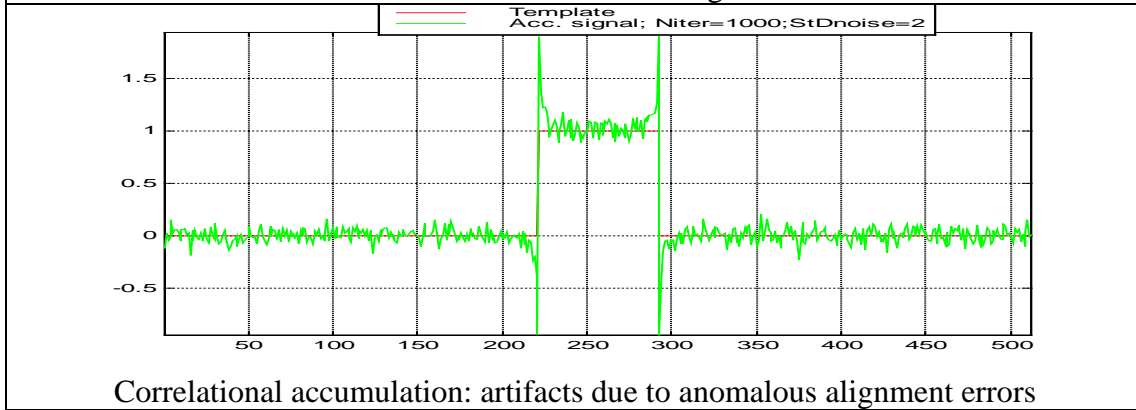
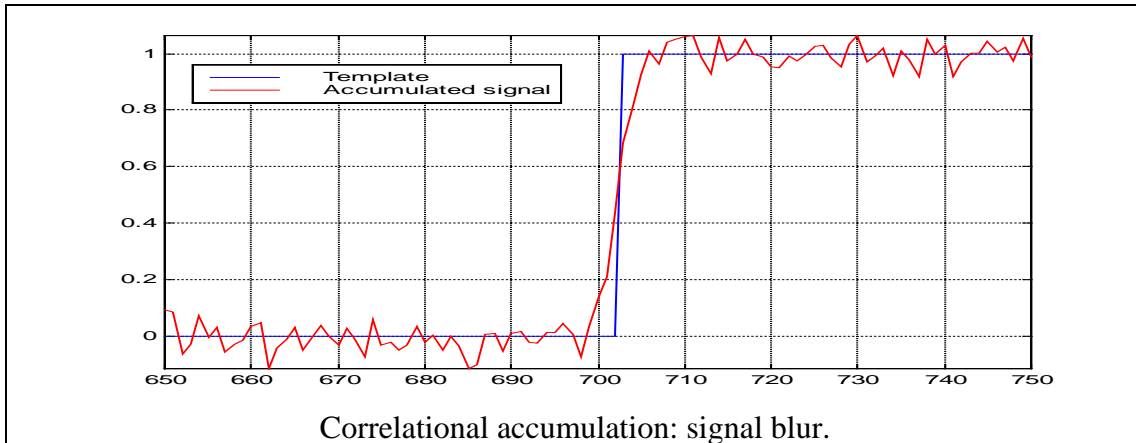
Correlational averaging in processing of electron micrographs



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

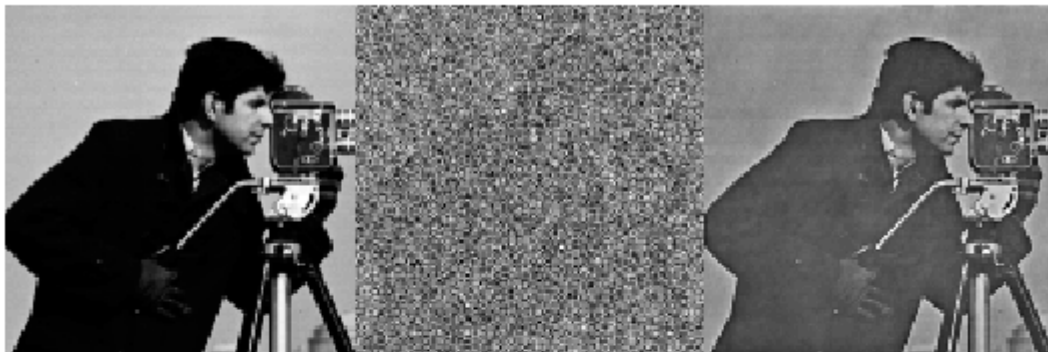


A typical electrocardiogram signal



Correlational accumulation: accumulation of template-correlated noise

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



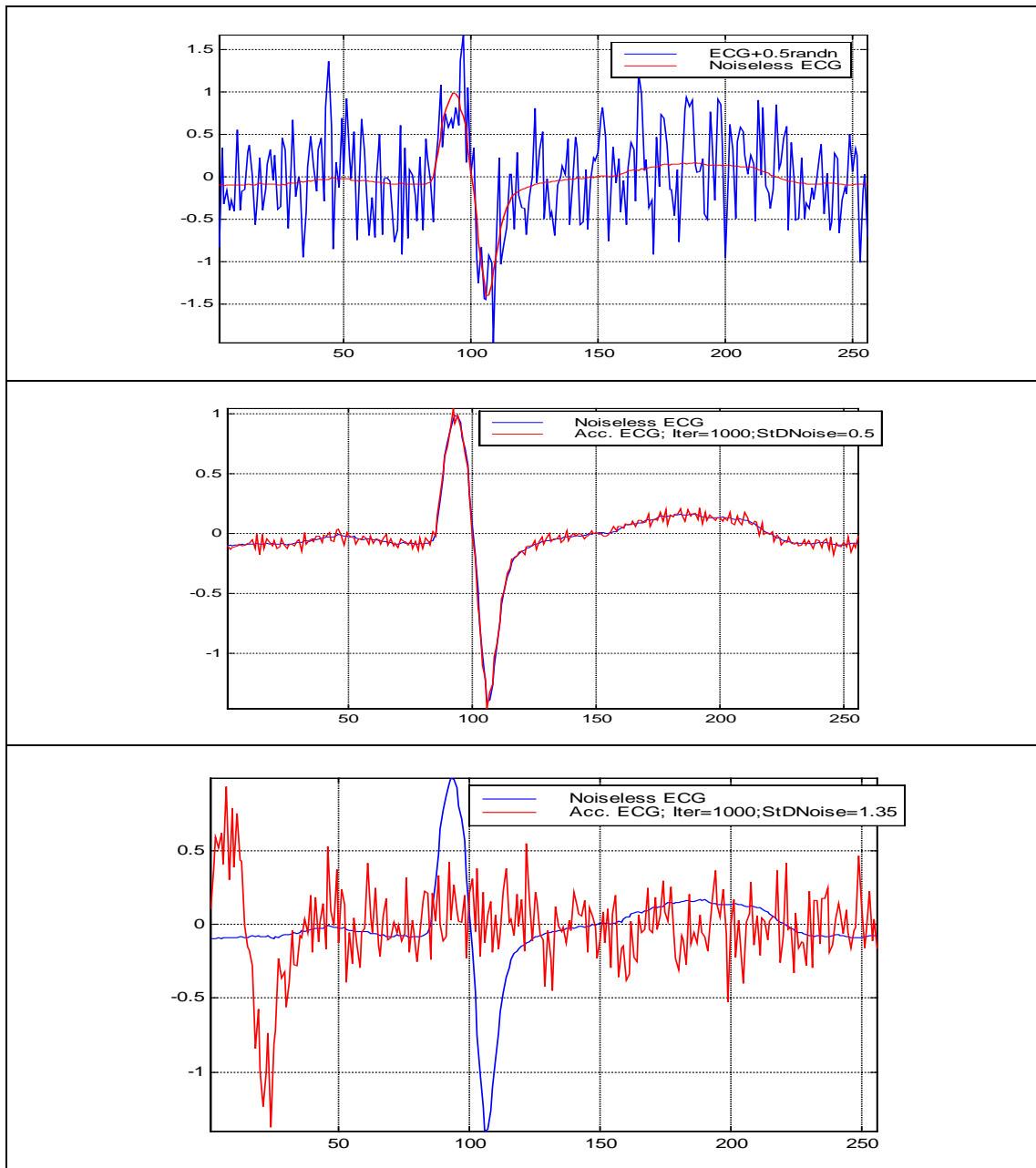
**Correlational accumulation; Nit=1000.
Template, accumulated image and 0.75-whitened template**

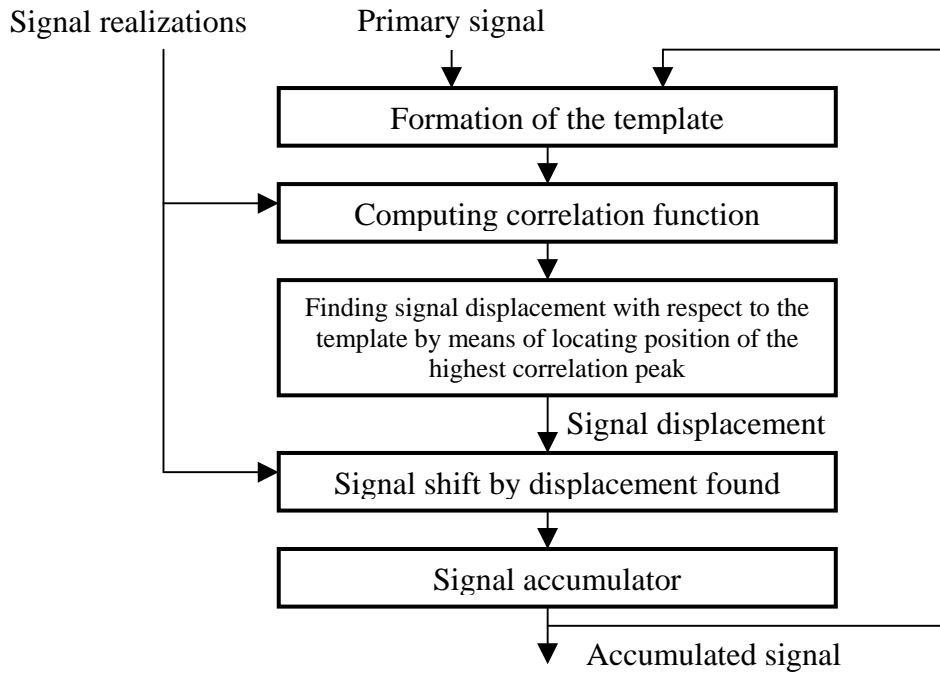


**Correlational accumulation; Nit=10000.
Template, accumulated image and 0.75-whitened template**

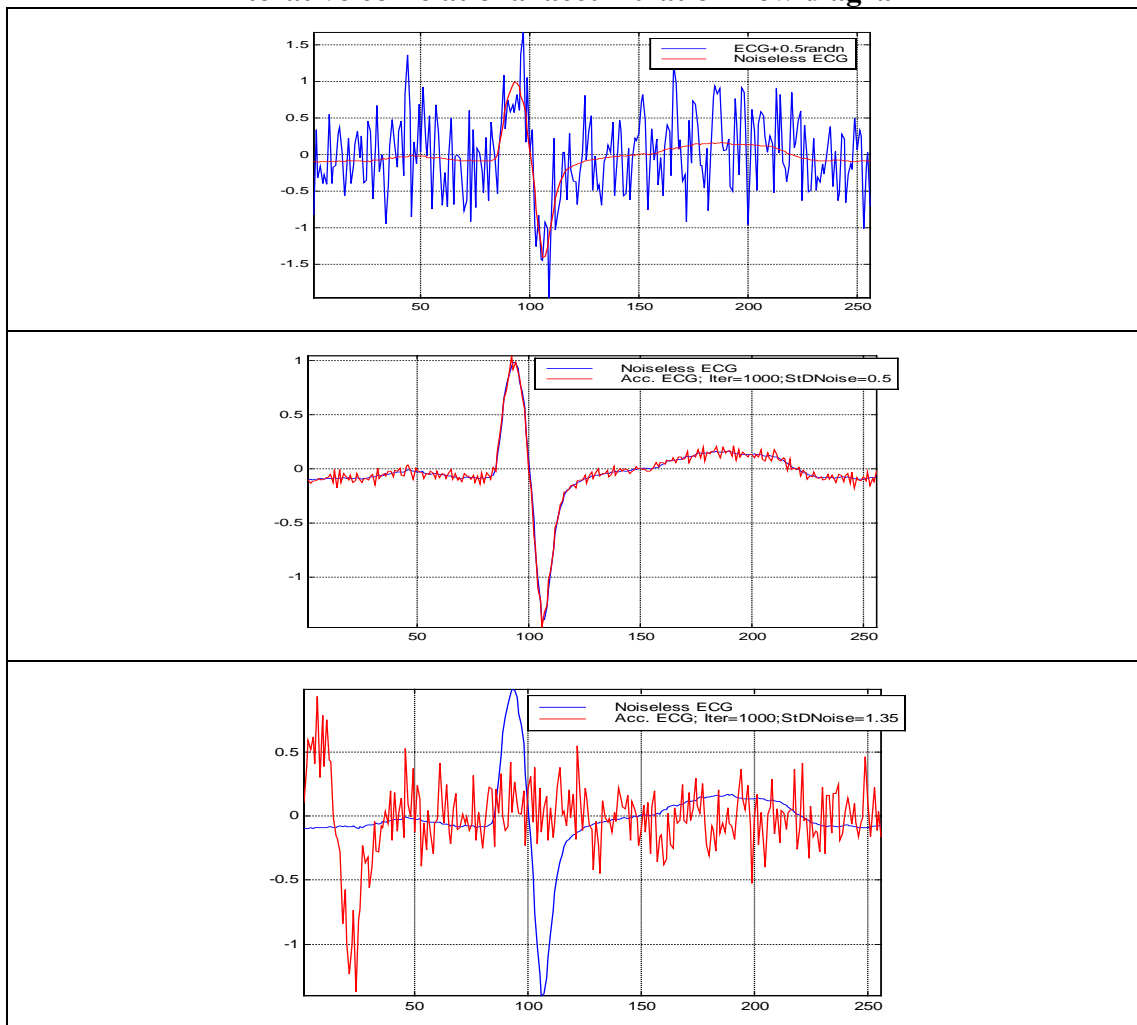


Iterative correlational accumulation: threshold effect

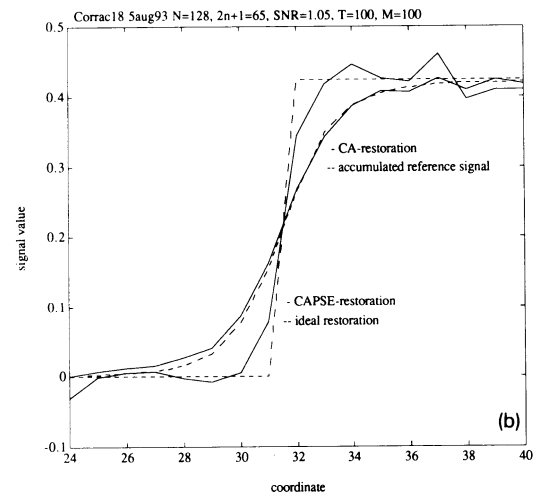
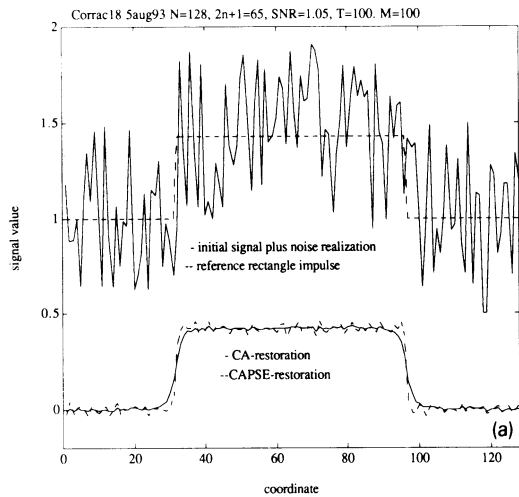
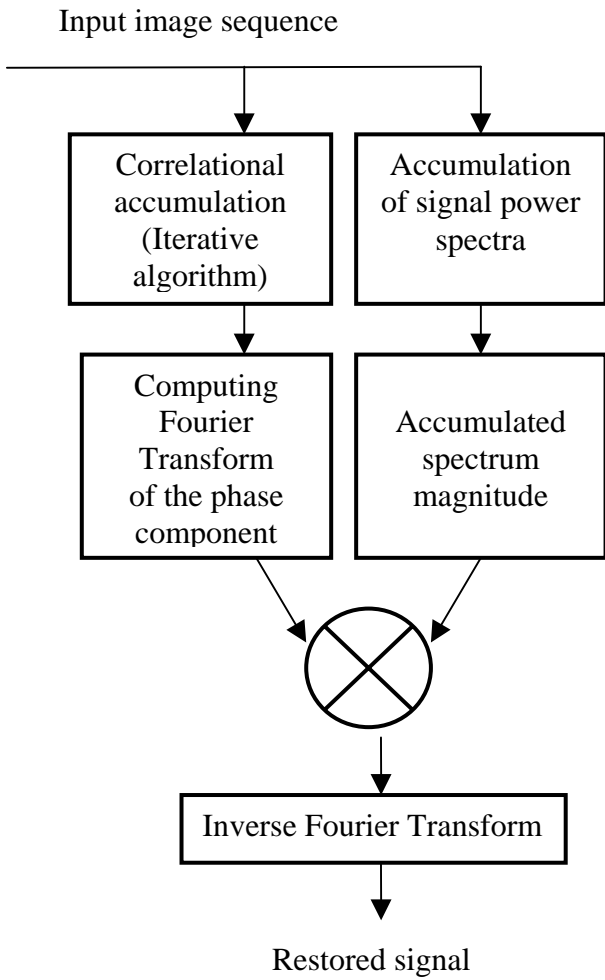




Iterative correlational accumulation flow diagram



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

$$\{\hat{a}_k^{(m)}\} = \arg \min_{\{b_k\} \Rightarrow \{a_k\}} \left\{ \text{AV}_{\Omega_A} \text{AV}_{\Omega_N} \left(\sum_{k=0}^{N_w-1} |a_k^{(m)} - \hat{a}_k^{(m)}|^2 \right) \right\}, \{k\} \in \text{Spatial/TemporalWindowAroundPixel } k$$

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

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

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

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>