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Video Coding with Motion Compensation for Groups of Pictures

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Motivation

- Today's video coding schemes utilize DPCM with MCP.
- How about motion-compensated 3-d transform coding?

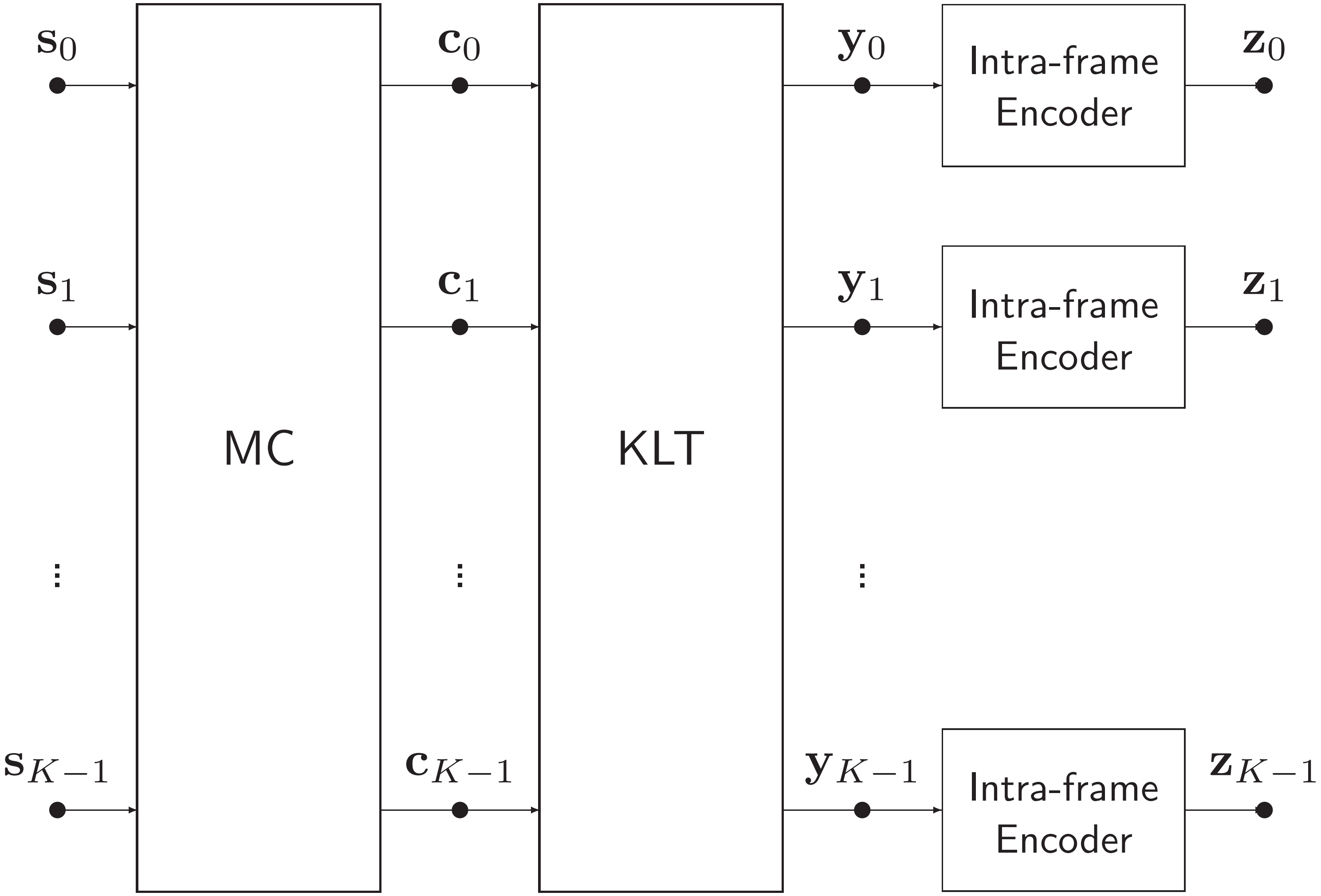
This talk . . .

provides an analysis based on a power spectral model.

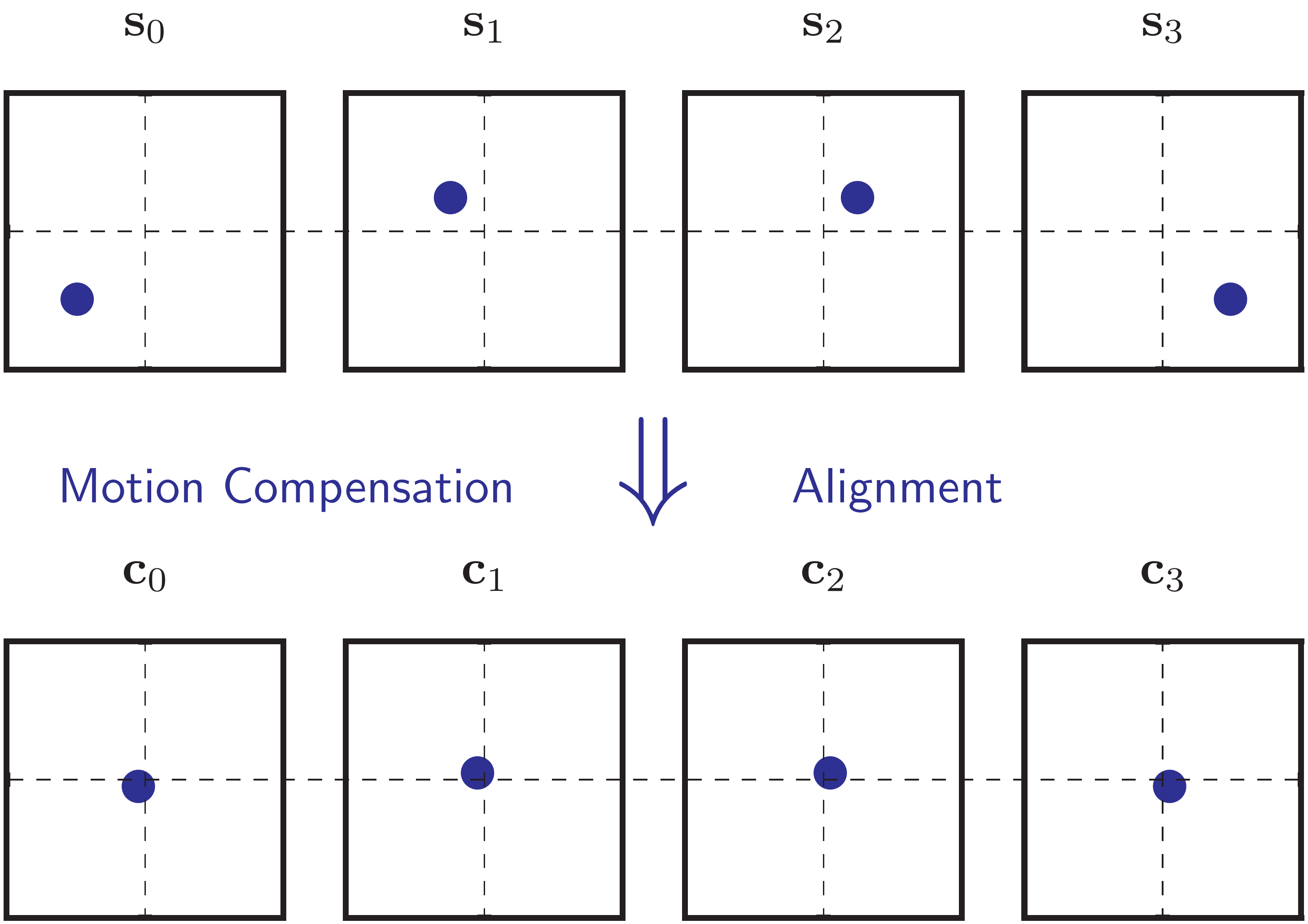
Overview

- Coding scheme for a group of pictures
- Model for a group of motion-compensated pictures
- Model assumptions
- Performance measure
- Performance and impact of residual noise
- Comparison to motion-compensated prediction

Coding Scheme for a Group of Pictures



Motion Compensation for a Group of Pictures

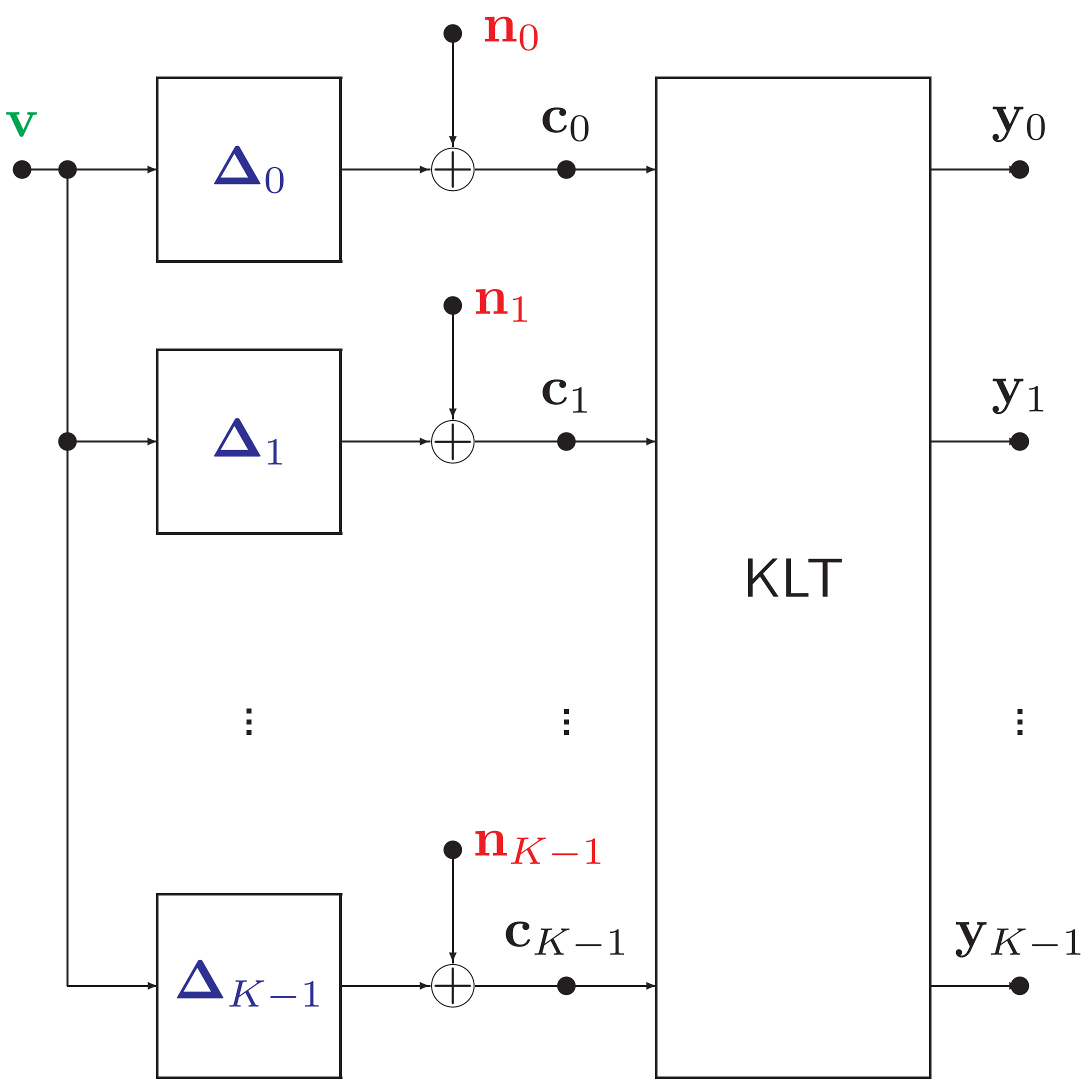


$\mathbf{s}_0$ $\mathbf{s}_1$ $\mathbf{s}_2$ $\mathbf{s}_3$

Motion Compensation $\Downarrow$ Alignment

$\mathbf{c}_0$ $\mathbf{c}_1$ $\mathbf{c}_2$ $\mathbf{c}_3$

Model for a Group of Motion-Compensated Pictures



$\mathbf{v}$	model picture
$\mathbf{\Delta}_k$	k-th displacement error
$\mathbf{n}_k$	k-th noise signal
$\mathbf{c}_k$	k-th motion-compensated signal
$\mathbf{y}_k$	k-th transform signal

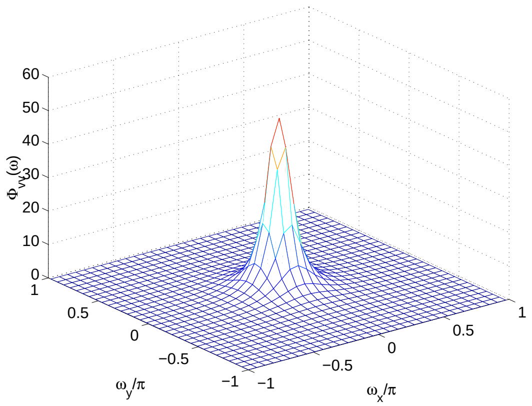
Codec has the freedom to determine its own reference picture!

Basic Model Assumptions

Model Picture

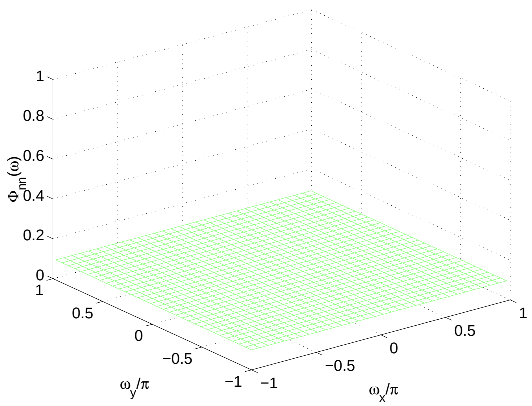
Bandlimited version of a 2-d signal with exponentially decaying and isotropic autocorrelation function.

Characterized by the PSD $\Phi_{\mathbf{vv}}(\omega)$ with variance $\sigma_{\mathbf{v}}^2 = 1$.



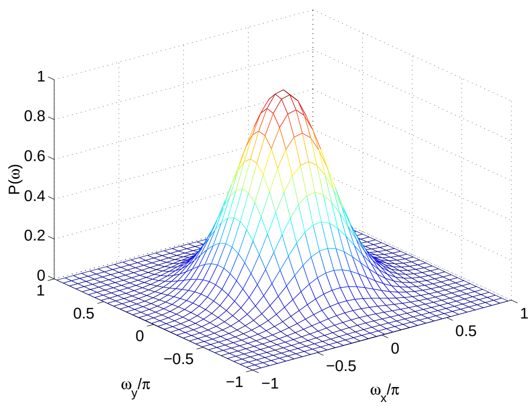
Residual Noise

White noise with variance $\sigma_{\mathbf{n}}^2$ and PSD $\Phi_{\mathbf{nn}}(\omega)$.



Displacement Error

Normal distributed and isotropic with variance $\sigma_{\boldsymbol{\Delta}}^2$ and characteristic function $P(\omega, \sigma_{\boldsymbol{\Delta}}^2)$.



Assumptions about Displacement Errors

- 2-d stationary normal distribution with variance $\sigma^2_{\mathbf{\Delta}}$ and zero mean for each motion-compensated picture

- x- and y-components are statistically independent

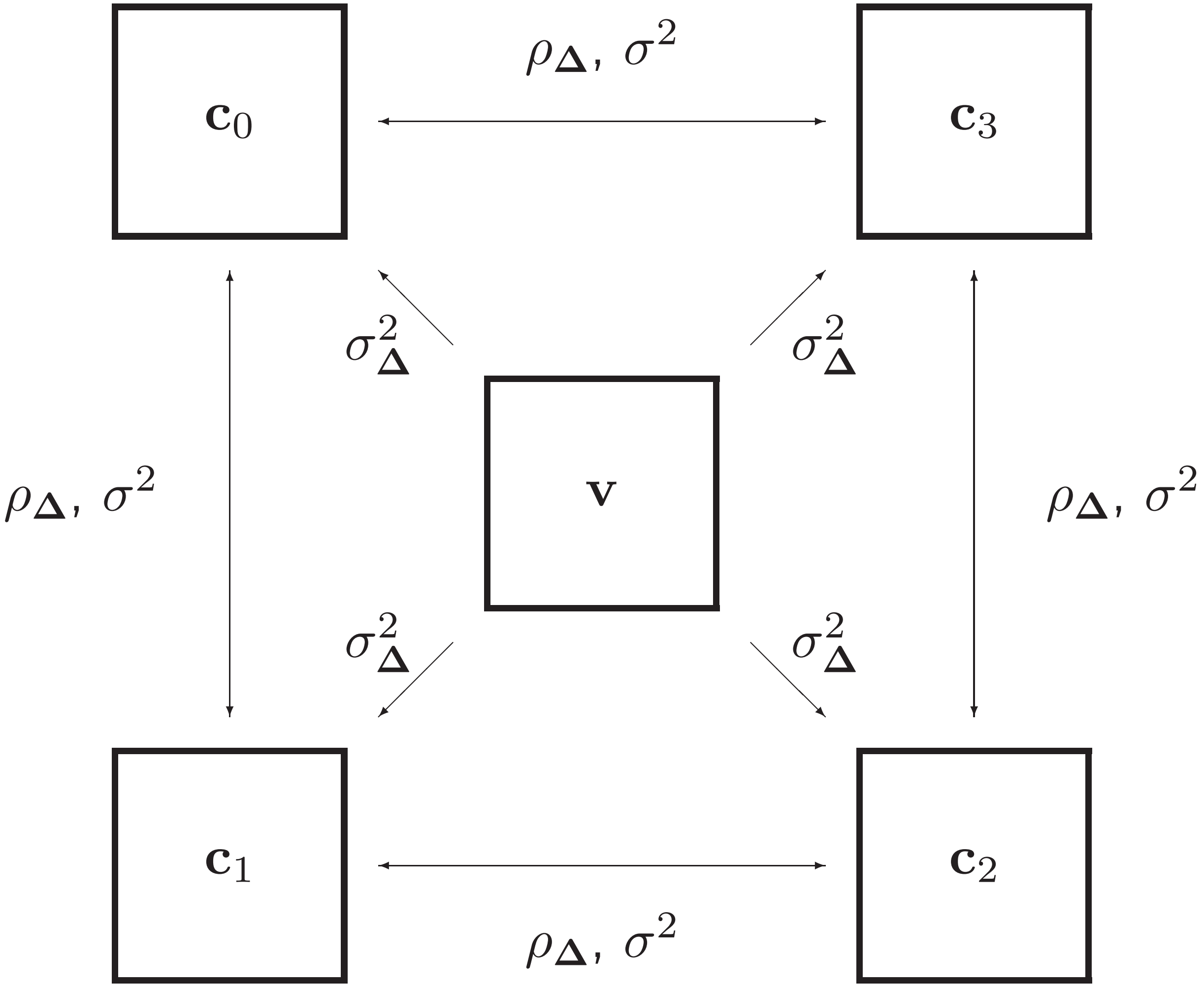
- Each displacement error pair is assumed to be jointly Gaussian with no preference among the K motion-compensated signals

- $K \times K$ covariance matrix of a displacement error component:

$$C_{\mathbf{\Delta}_x\mathbf{\Delta}_x} = C_{\mathbf{\Delta}_y\mathbf{\Delta}_y} = \sigma^2_{\mathbf{\Delta}} \begin{pmatrix} 1 & \rho_{\mathbf{\Delta}} & \cdots & \rho_{\mathbf{\Delta}} \\ \rho_{\mathbf{\Delta}} & 1 & \cdots & \rho_{\mathbf{\Delta}} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{\mathbf{\Delta}} & \rho_{\mathbf{\Delta}} & \cdots & 1 \end{pmatrix}$$

- Covariance matrix is nonnegative definite: $\frac{1}{1-K} \leq \rho_{\mathbf{\Delta}} \leq 1 \quad K > 1$

Displacement Inaccuracy and Correlation



Absolute displacement inaccuracy

$$\sigma^2_{\mathbf{\Delta}} = E\left\{\mathbf{\Delta}_{\mathbf{x}_\mu}^2\right\}$$

Relative displacement inaccuracy

$$\sigma^2 = E\left\{(\mathbf{\Delta}_{\mathbf{x}_\mu} - \mathbf{\Delta}_{\mathbf{x}_\nu})^2\right\}$$

Performance Measure

- Rate difference for each picture k

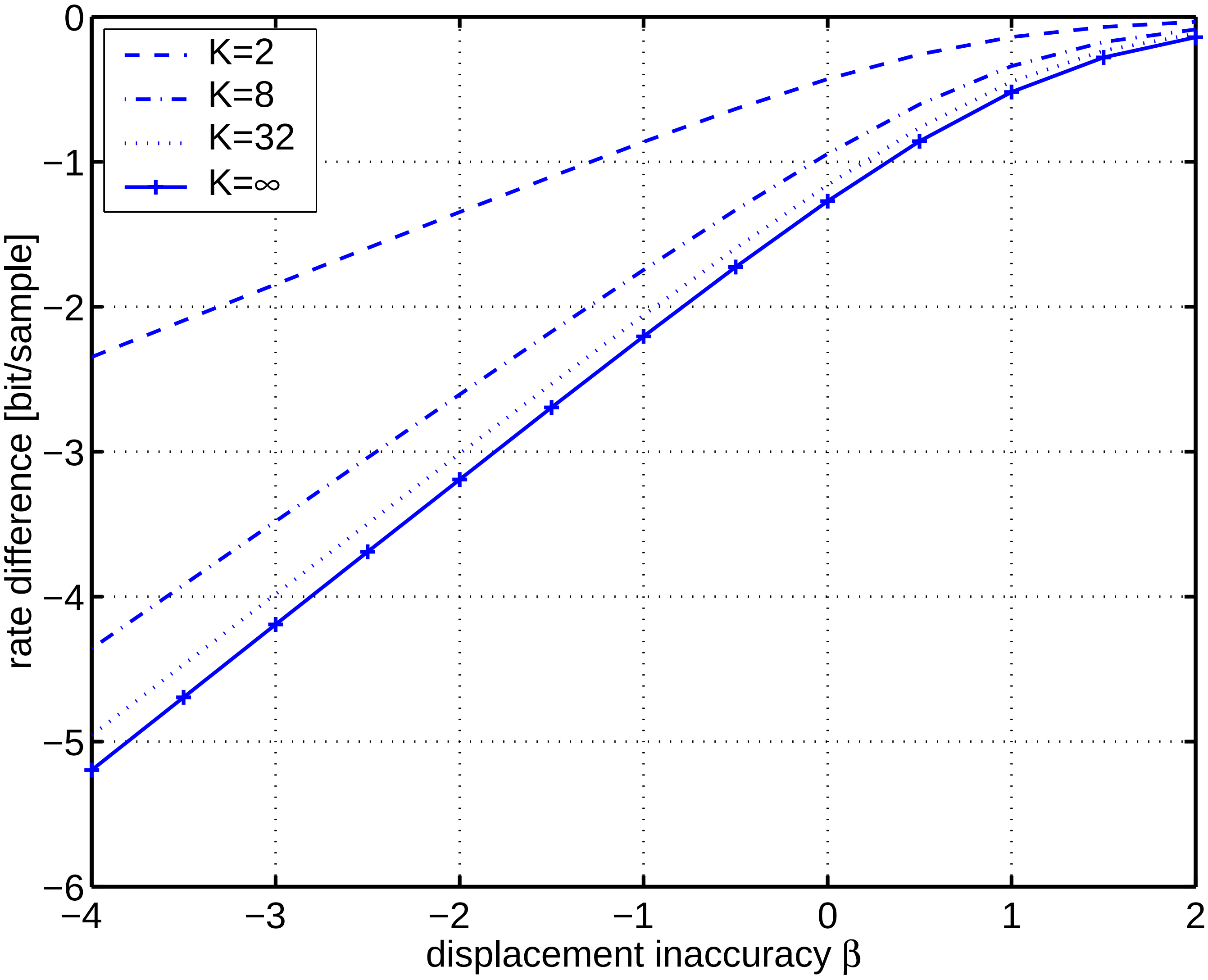
$$\Delta R_k = \frac{1}{4\pi^2} \int_{-\pi}^{\pi} \int_{-\pi}^{\pi} \frac{1}{2} \log_2 \left(\frac{\Phi_{\mathbf{y}_k \mathbf{y}_k}(\omega)}{\Phi_{\mathbf{c}_k \mathbf{c}_k}(\omega)} \right) d\omega$$

→ Measures maximum bit-rate reduction
→ Compared to optimum intra-frame encoding
→ For the same mean squared reconstruction error
→ For Gaussian signals

- Average rate difference

$$\Delta R = \frac{1}{K} \sum_{k=0}^{K-1} \Delta R_k$$

Performance with Negligible Residual Noise



Identical absolute and relative displacement inaccuracy

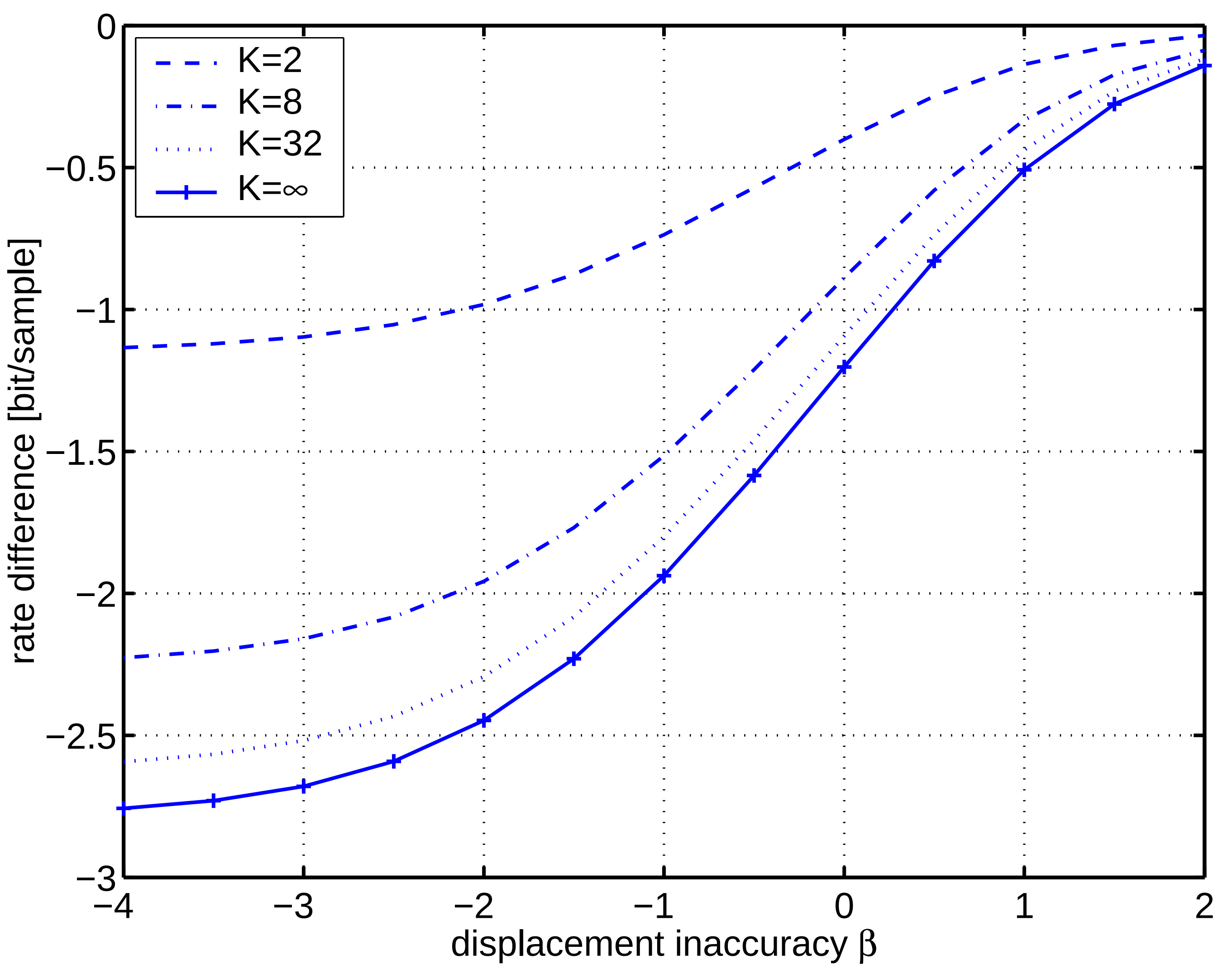
Calibration:

$$\beta = \frac{1}{2}\log_2(12\sigma^2_{\mathbf{\Delta}})$$

Accuracy:

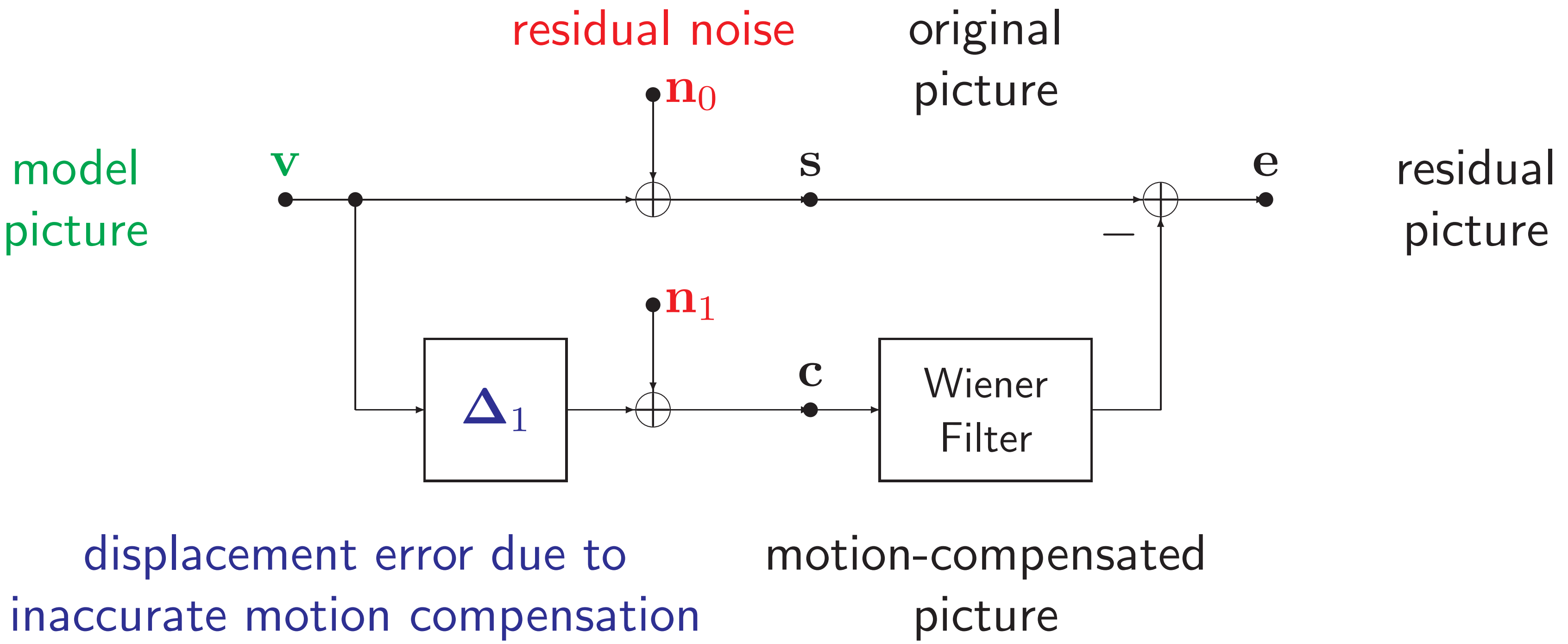
$\beta = 0$: IP
$\beta = -1$: HP
$\beta = -2$: QP

Performance with Residual Noise -30 dB



Identical absolute and relative displacement inaccuracy

Motion-Compensated Prediction



residual noise

original picture

model picture

$\mathbf{v}$

$\mathbf{n}_0$

$\mathbf{s}$

$\mathbf{e}$

residual picture

$-$

$\mathbf{n}_1$

$\mathbf{c}$

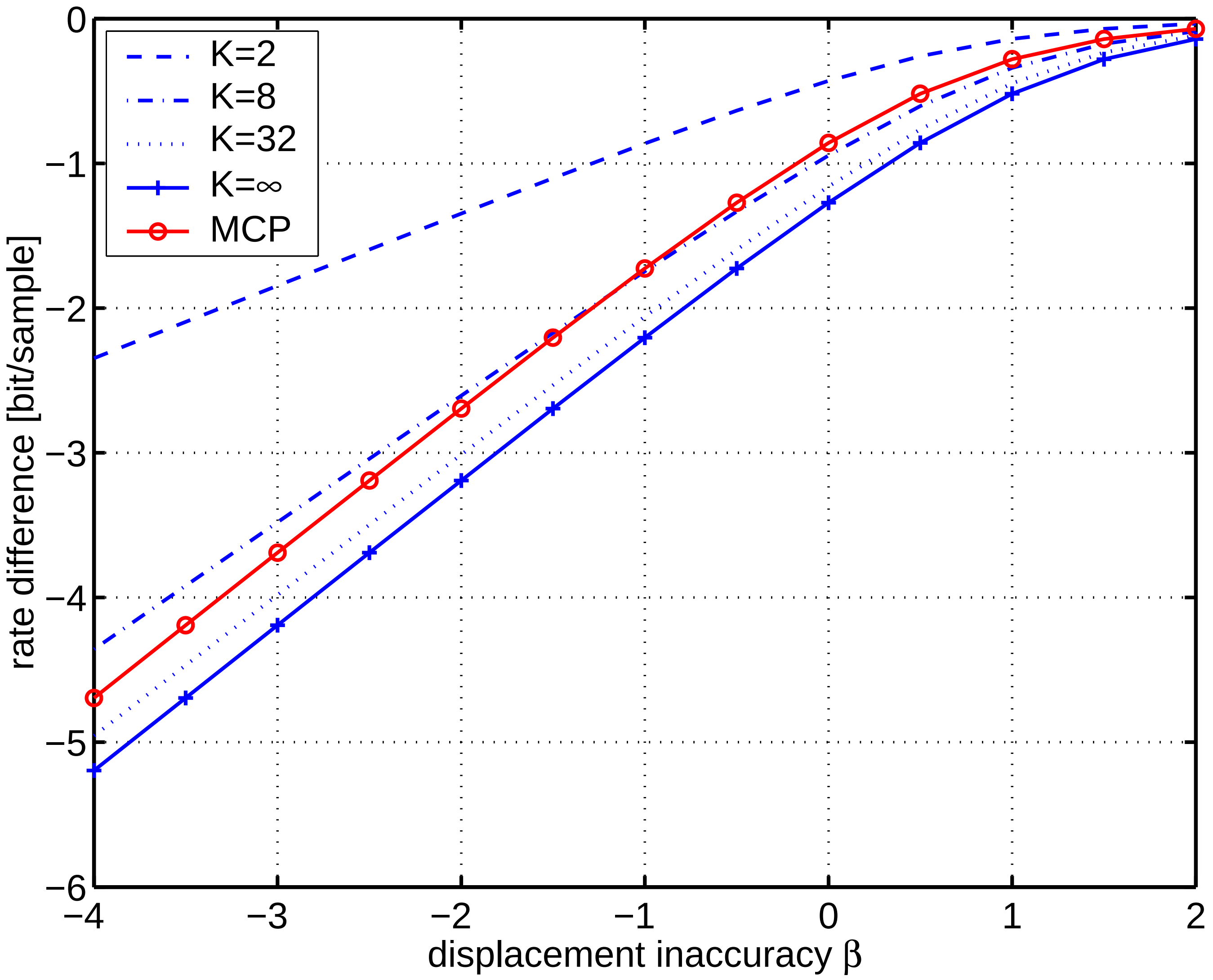
$\mathbf{\Delta}_1$

Wiener Filter

displacement error due to inaccurate motion compensation

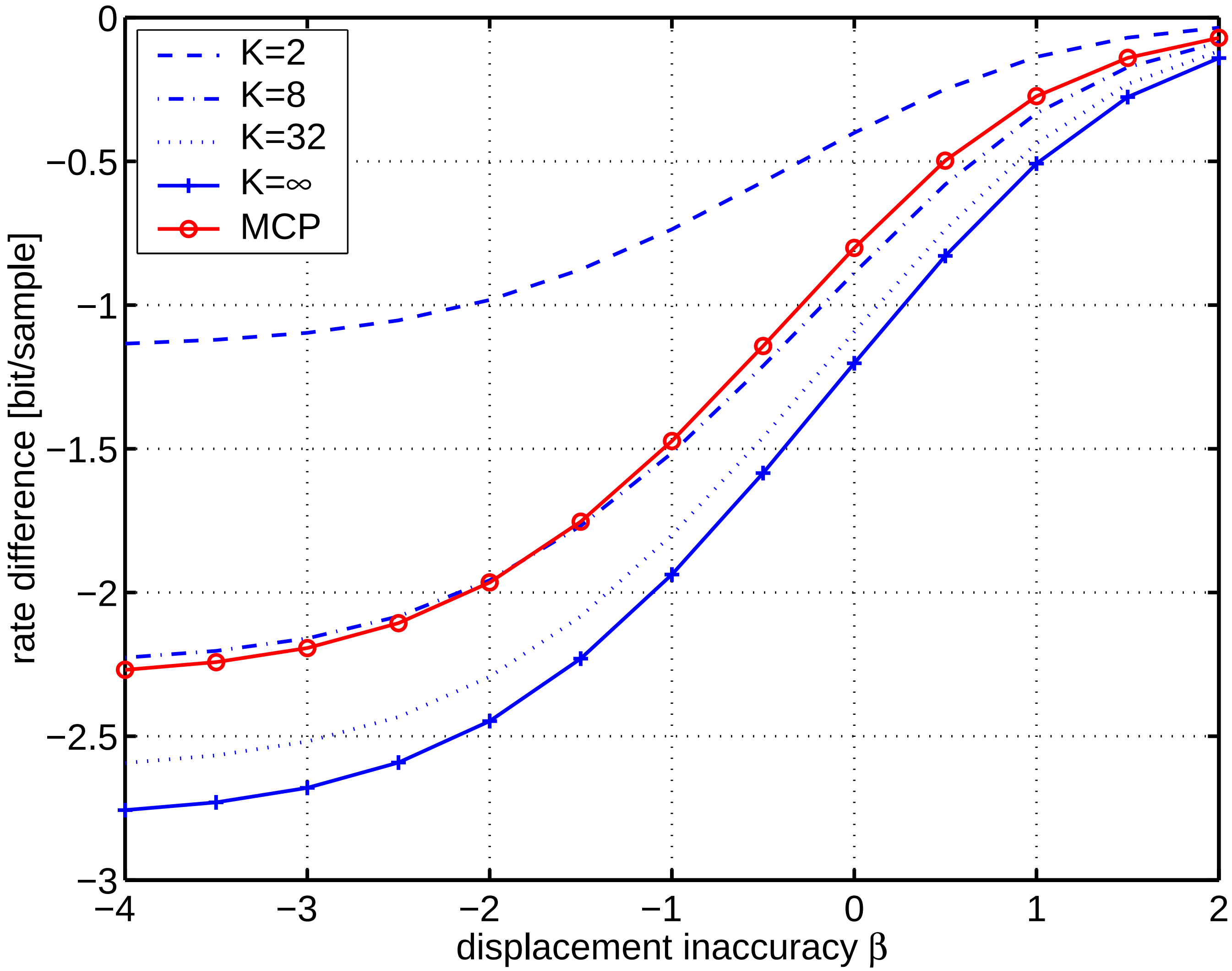
motion-compensated picture

Comparison to Motion-Compensated Prediction I



Absolute and relative displacement inaccuracy are identical,
residual noise level -100 dB

Comparison to Motion-Compensated Prediction II



Absolute and relative displacement inaccuracy are identical,
residual noise level -30 dB

Summary and Conclusions

- Model for a group of motion-compensated pictures with correlated displacement error

- Motion-compensated pictures are decorrelated by the Karhunen-Loeve Transform

- Results of the analysis:

  1. Without residual noise, the slope of the rate difference achieves up to 1 bit/sample and displacement inaccuracy step
  2. Residual noise limits the gain by accurate motion compensation

- Comparison to motion-compensated prediction:

  1. The transform model outperforms MCP with optimum Wiener filter by at most 0.5 bit/sample
  2. The performance for a group of $K = 8$ pictures is comparable to MCP