Picture Coding Symposium 2003

Investigation of Motion-Compensated Lifted Wavelet Transforms

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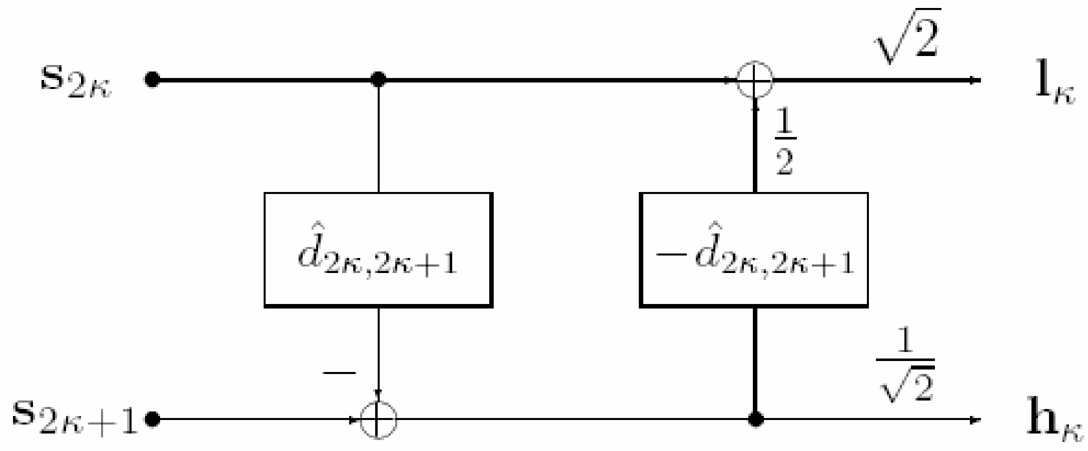
Outline

- Coding scheme with motion-compensated wavelets
- Experimental results for temporal Haar and 5/3 wavelets
- Signal model and performance bounds
- Comparison to predictive coding

Coding Scheme

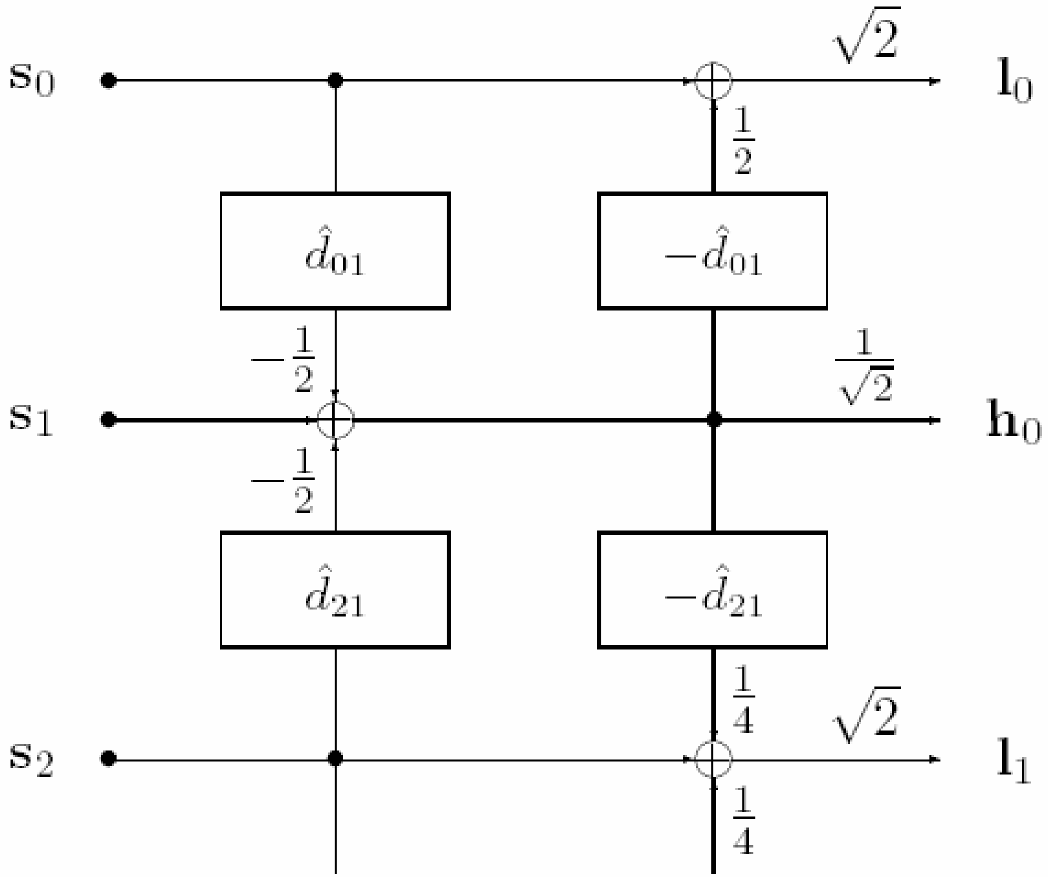
- Dyadic decomposition for each group of K pictures
- Motion-compensated Haar and 5/3 wavelet
- 16x16 block motion compensation with half-pel accuracy
- Intra-frame coding with 8x8 DCT and run-length coding
- Same quantizer step-size for all K intra-frame encoder

Motion-Compensated Haar Wavelet



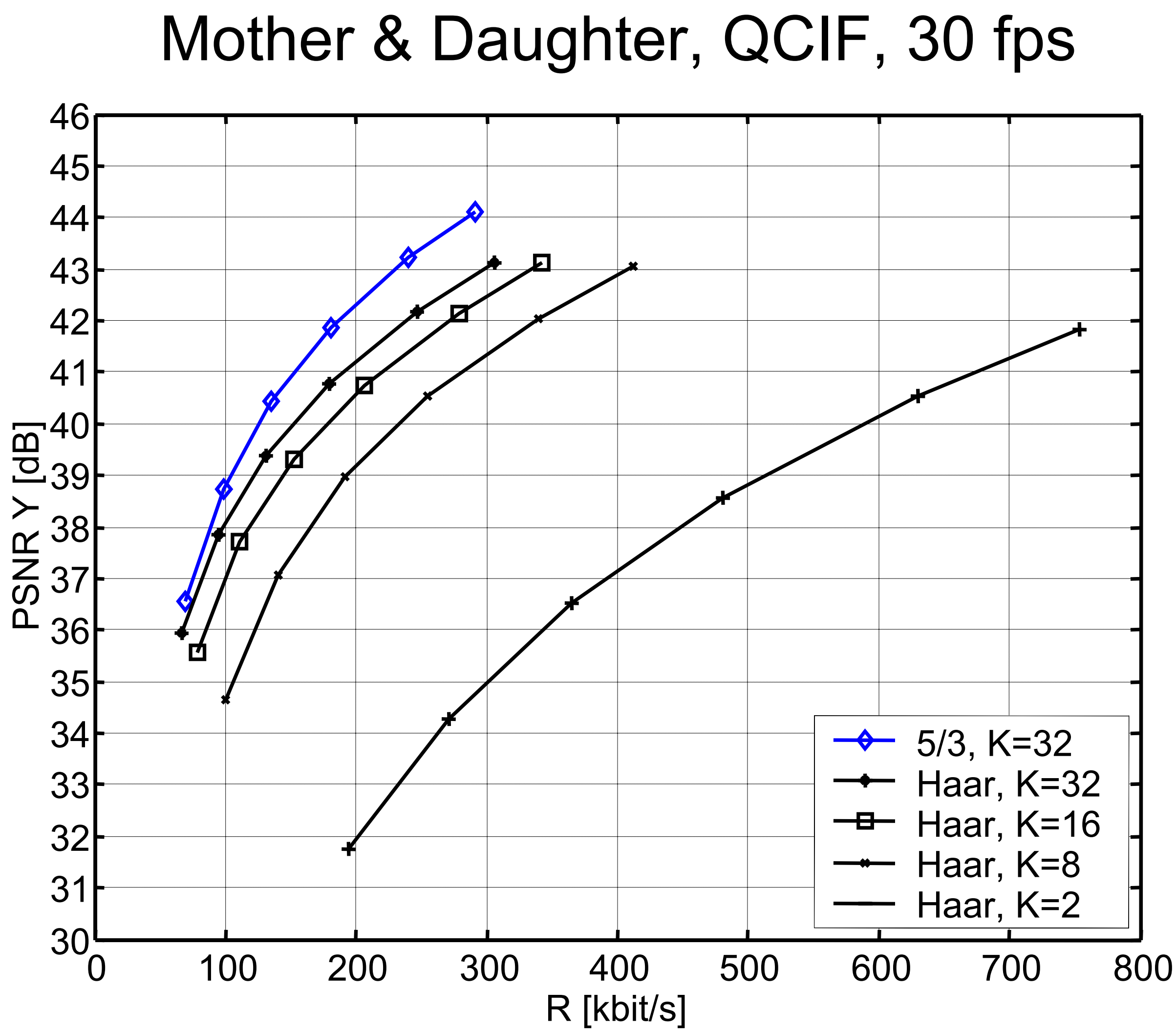
Update step uses negative motion vector of corresponding prediction step

Motion-Compensated 5/3 Wavelet

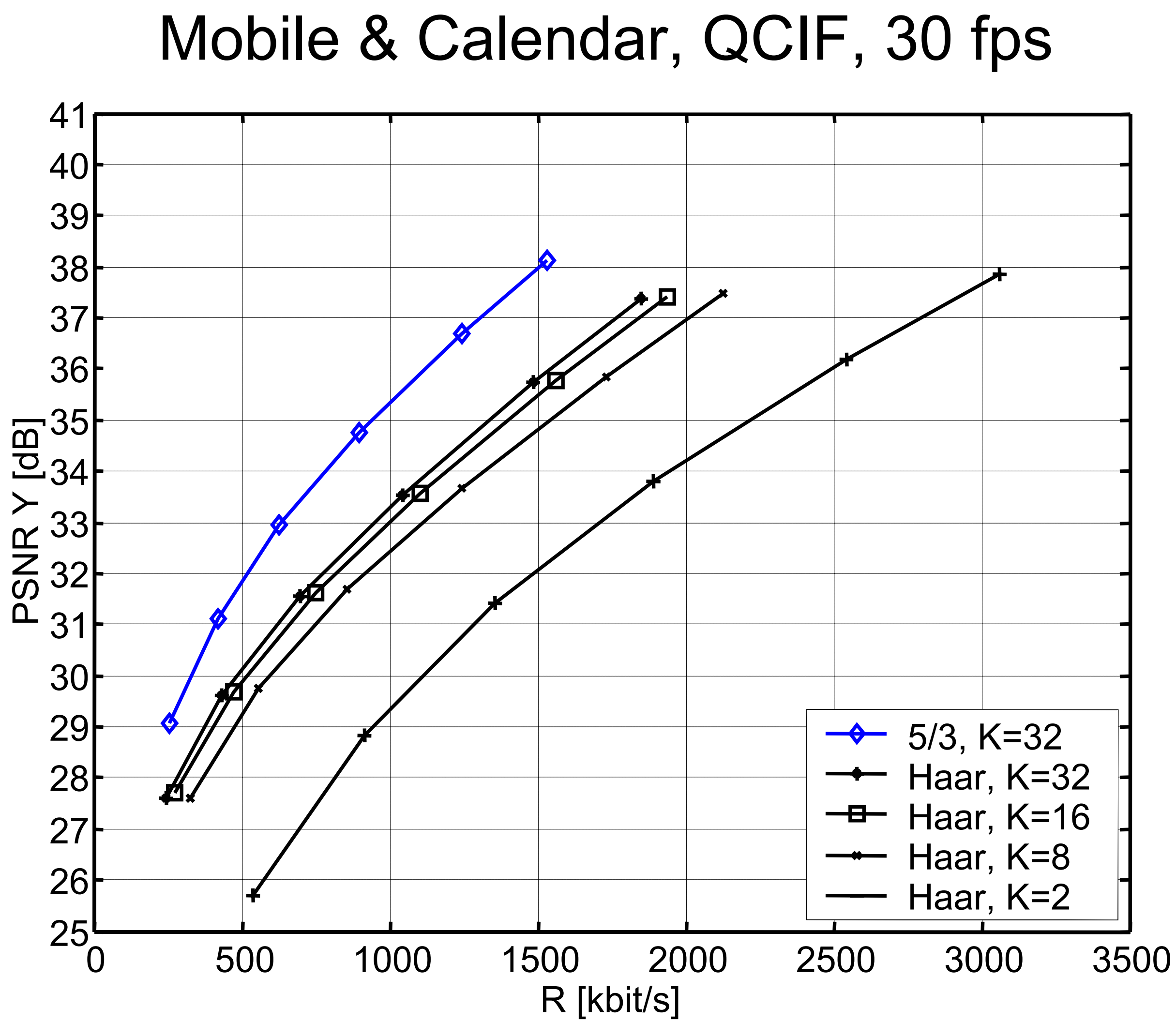


Update steps uses negative motion vectors of corresponding prediction steps

Motion-Compensated Haar & 5/3 Wavelet



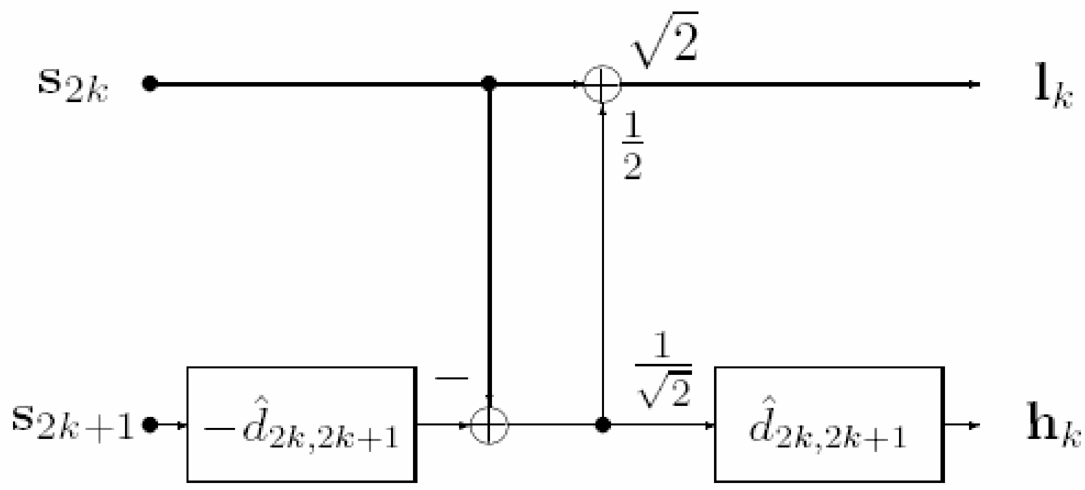
Motion-Compensated Haar & 5/3 Wavelet



Theoretical Signal Model

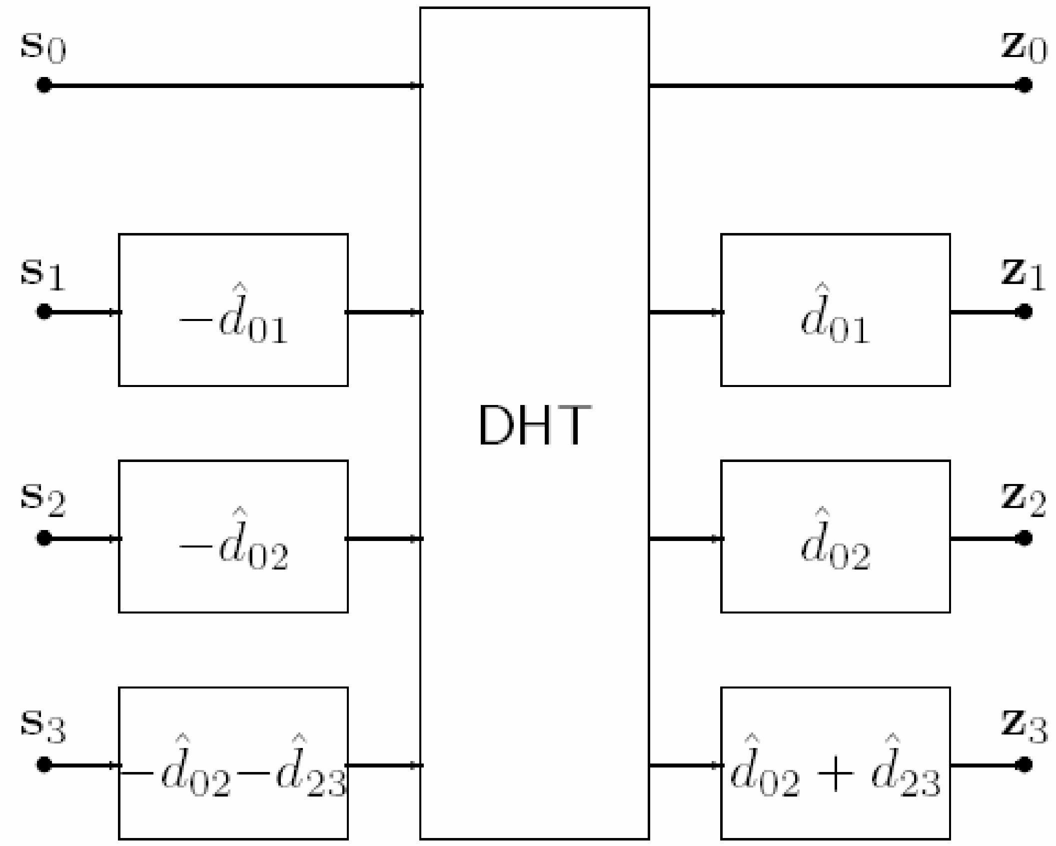
- Let $s_k[x,y]$ be the k-th picture at pel-location x,y
- The signals are space-discrete and band-limited
- Ideal reconstruction is used for sub-pel accurate displacements
- Displacement operation is invertible

Equivalent Motion-Compensated Wavelets



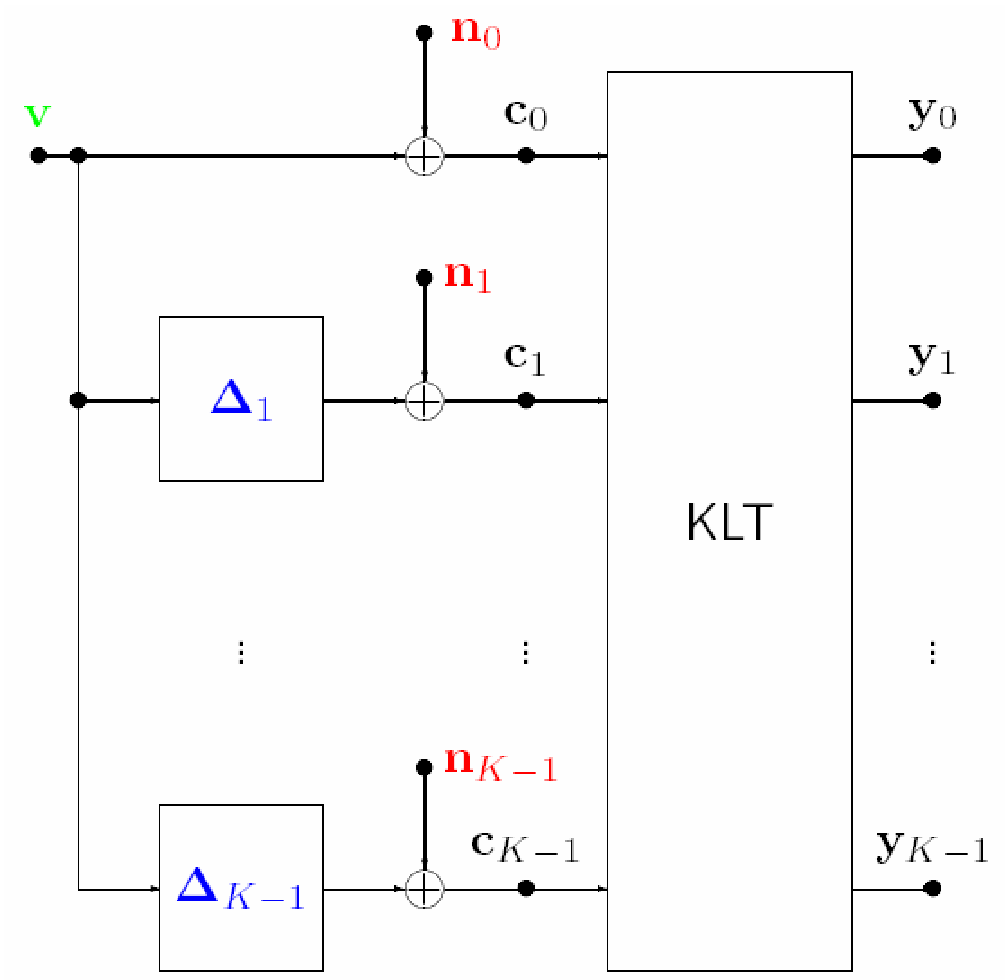
Invertible displacement operations are assumed

Dyadic Haar Transform



Both, true displacements d and estimated displacements $\hat{d}$ are additive

Generalized Signal Model



$\mathbf{v}$	model picture
Δ_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

Any input picture can be reference picture

Performance Measure

- Rate difference for each picture k

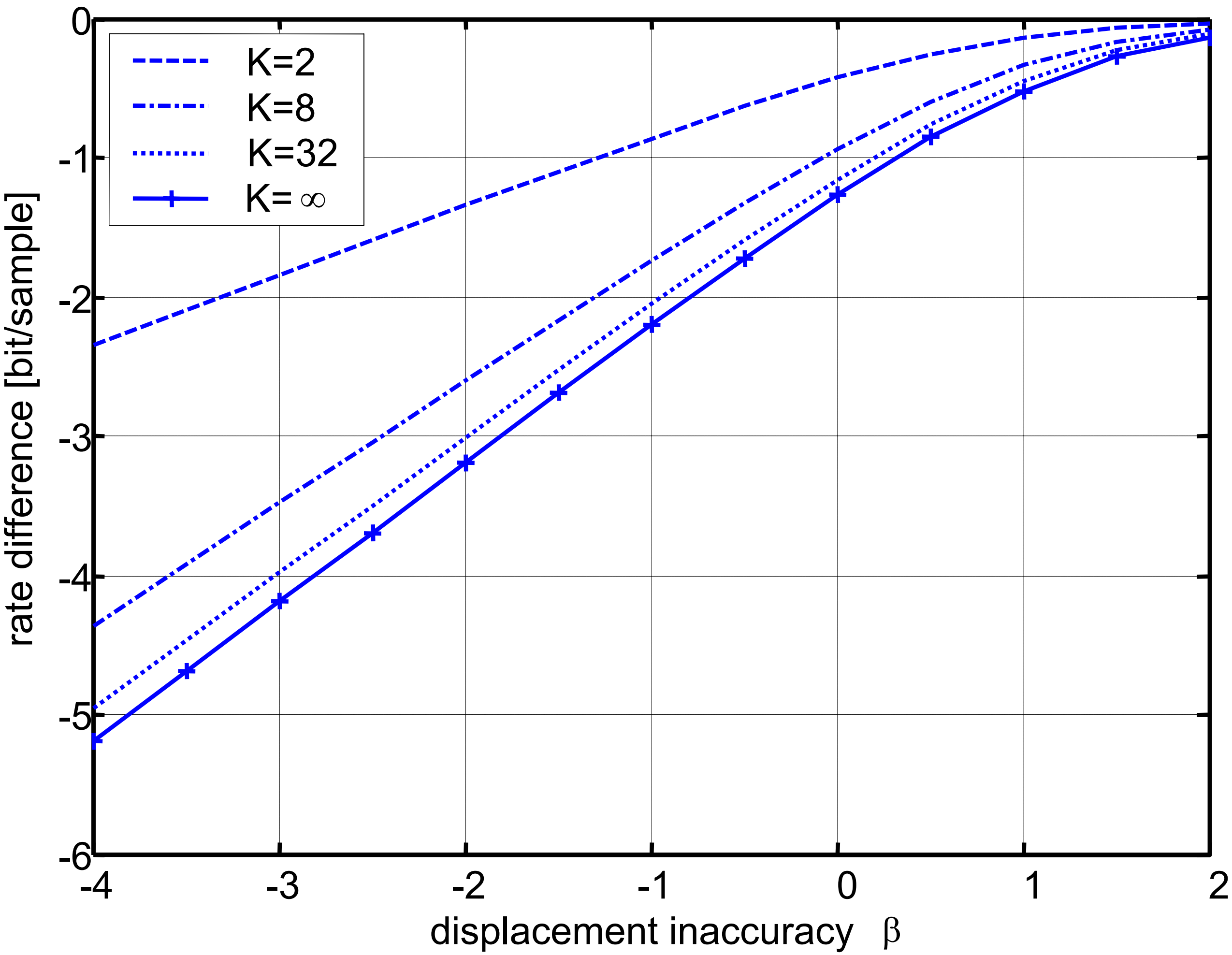
$$\Delta R_k = \frac{1}{4\pi^2} \int_{-\pi}^{\pi} \int_{-\pi}^{\pi} \frac{1}{2} \log_2 \left(\frac{\Phi_{\mathbf{y}_k \mathbf{y}_k}(\omega)}{\Phi_{\mathbf{c}_k \mathbf{c}_k}(\omega)} \right) d\omega$$

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

- Average rate difference

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

Rate Difference with Negligible Noise

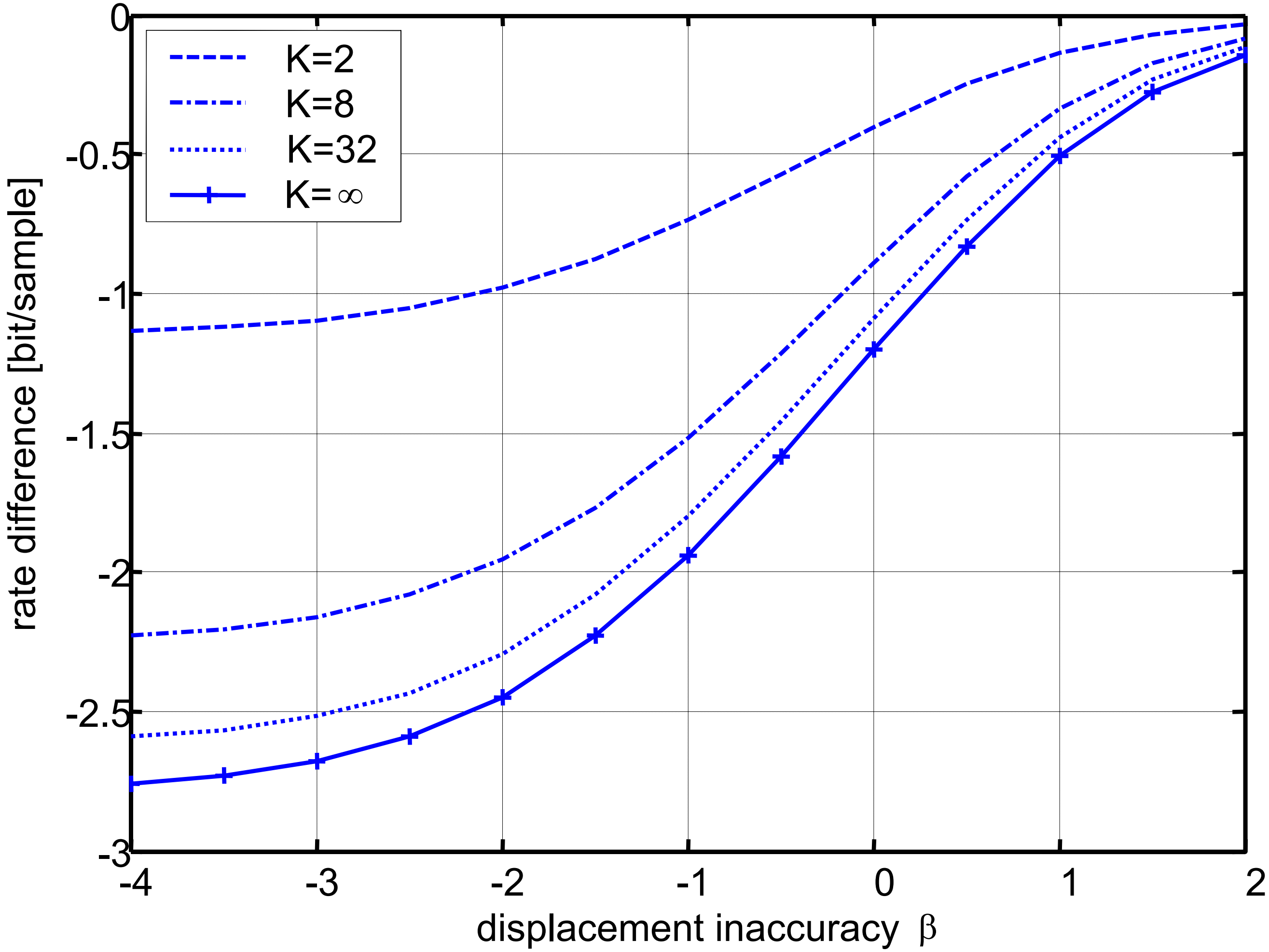


Calibration:

$\beta = 0.5 \log_2(12\, \sigma^2_\Delta)$

Integer-pel	$\beta=0$
Half-pel	$\beta=-1$
Quarter-pel	$\beta=-2$

Rate Difference with RNL = -30 dB



Calibration:

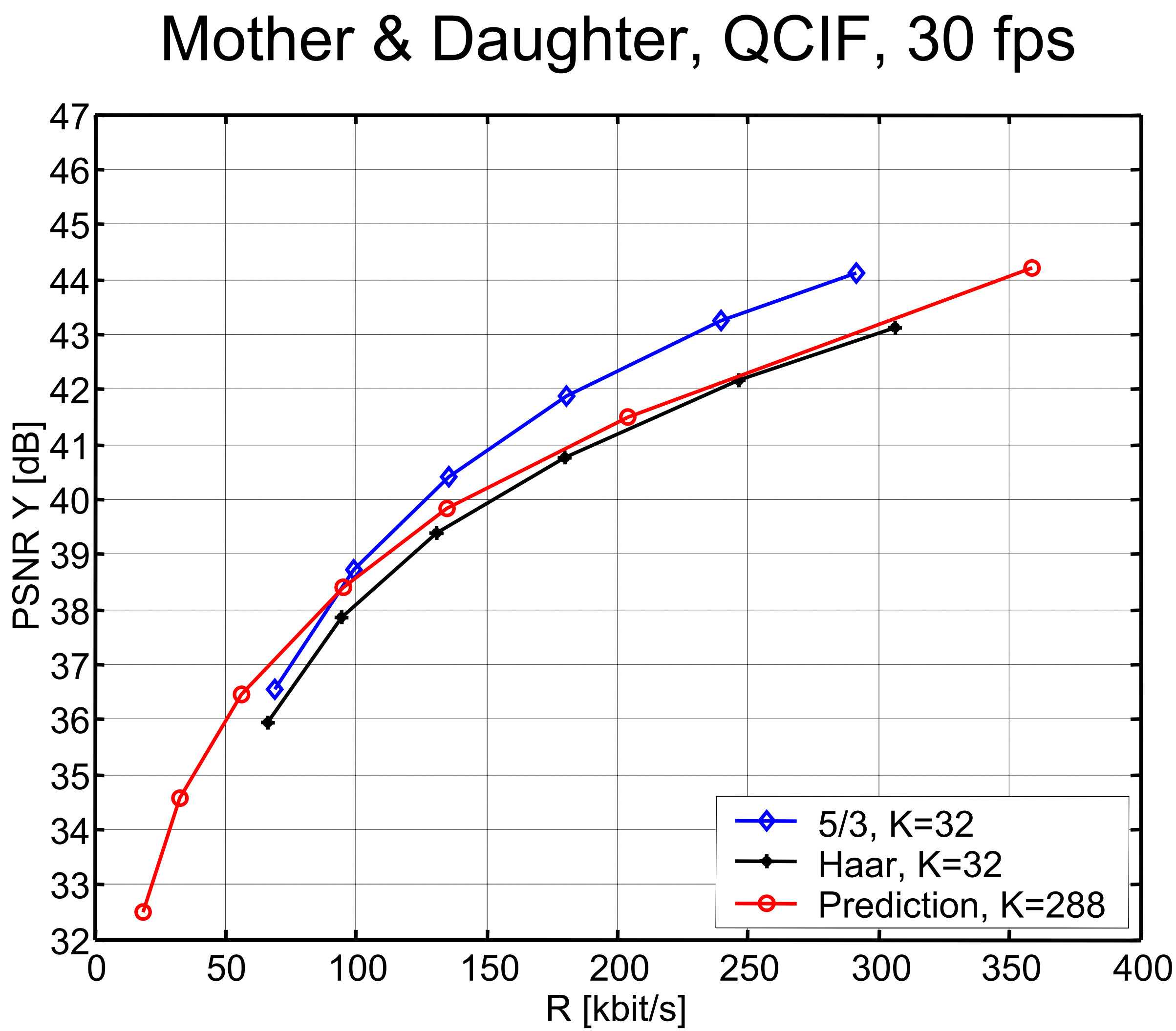
$\beta = 0.5 \log_2(12\,\sigma^2_\Delta)$

Integer-pel	$\beta=0$
Half-pel	$\beta=-1$
Quarter-pel	$\beta=-2$

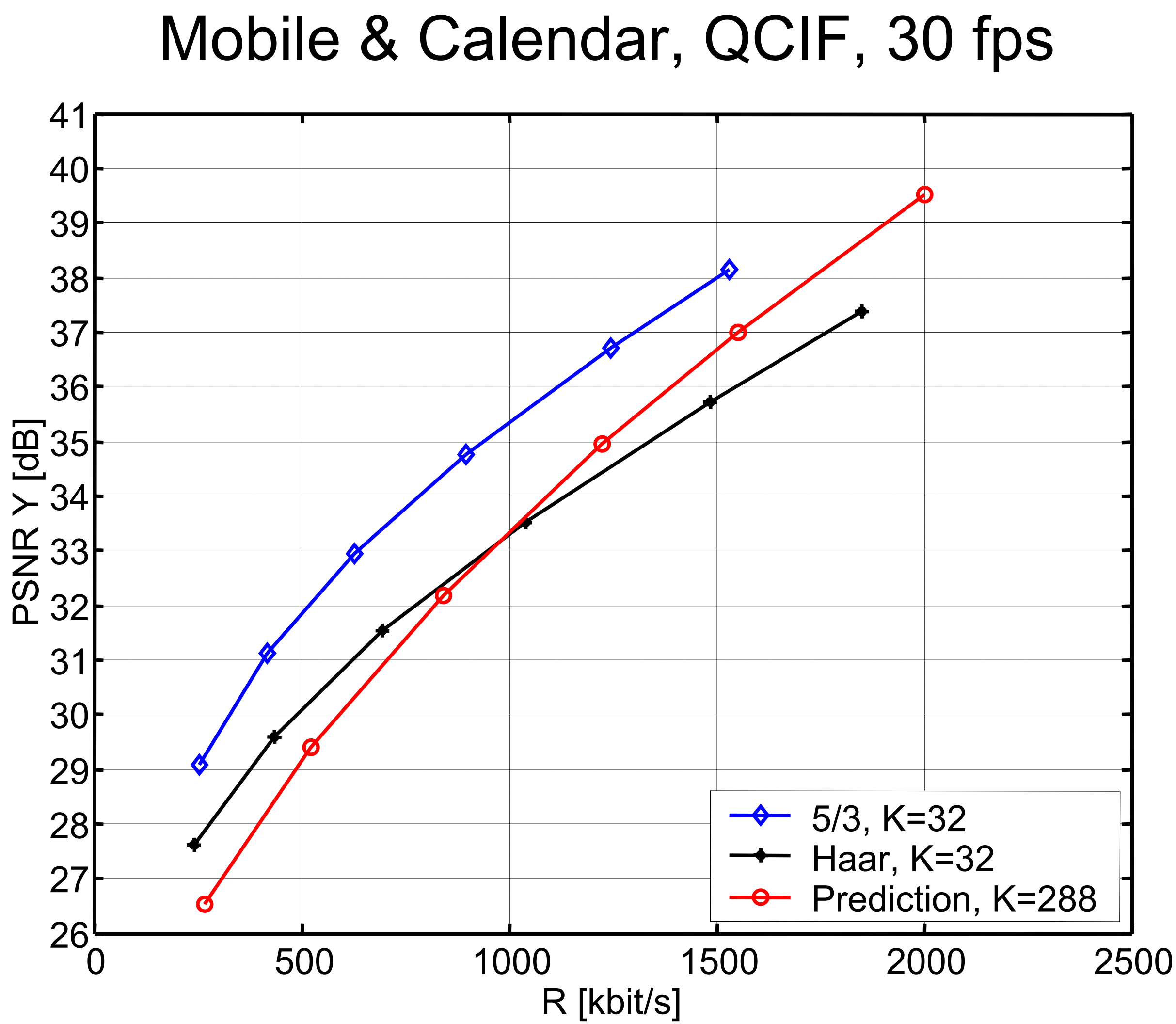
Comparison to Predictive Coding

- Predictive coding scheme:
  - 16x16 block motion compensation with half-pel accuracy
  - Previous reference frame only
  - Intra-frame coding with 8x8 DCT and run-length coding
  - Only one intra-frame in the beginning of the sequence
  - Same quantizer step-size for all inter-frames
- Motion-compensated wavelet coding scheme uses the same components

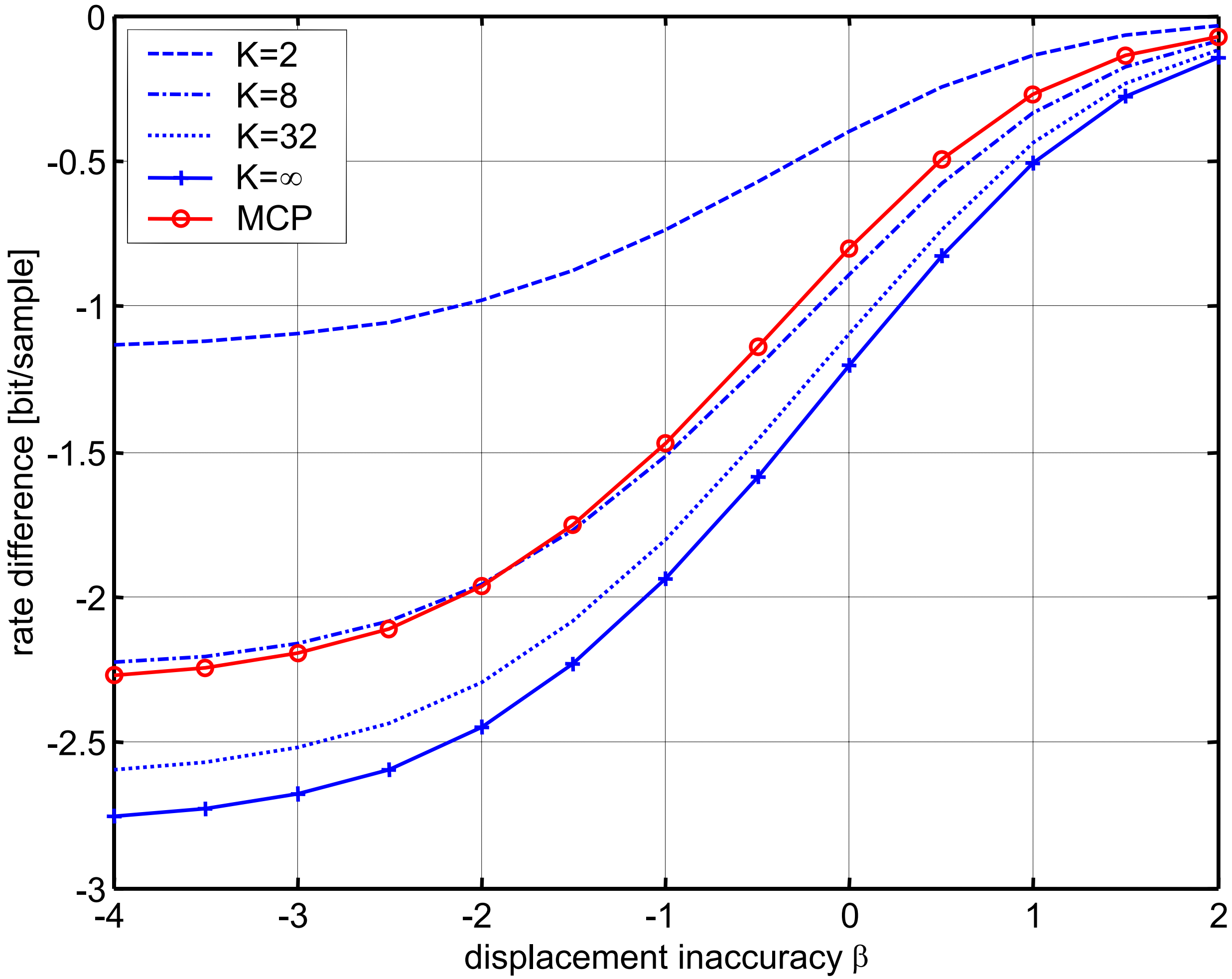
Comparison to Predictive Coding



Comparison to Predictive Coding



Comparison to Predictive Coding



RNL = -30 dB

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Conclusions

- Rate difference is limited to 1 bit per sample per displacement inaccuracy step
- Gain by accurate motion compensation is limited by residual noise
- Motion-compensated 3-d transform coding outperforms predictive coding by at most 0.5 bits per sample