Title
Important Distortion Factors in the Encoding of Very High Quality Images

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next up previous
Next: THE PQS SYSTEM **Up:** Important Distortion Factors in **Previous:** Important Distortion Factors in

INTRODUCTION

- Image impairments due to coders are spatially local and described as "end of block errors", "ringing", "jagged edges","random errors" etc.
- Image impairements can be quantified by distortion factors Fi.
- A Picture Quality Scale(P Q S) which combine distortion factors into a single, perceptually meaningful, numerical measure has been reported previously.
- At high image quality, not all impairments are perceptible.

  This paper examines distortion factors important at high quality to
  -Predict perceptible impairments
  -Modify and simplify a Picture Quality Scale
  -Allow new design methods

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Tue Sep 20 00:45:13 PDT 1994

next up previous

Next: IMPORTANT FACTORS AT **Up:** Important Distortion Factors in **Previous:** INTRODUCTION

THE PQS SYSTEM

- The visibility of image impairments due to coding depends on coding errors and properties of the Human Visual System(HVS).
- Coding errors are perceptually weighted to account for Weber's Law in the perception of luminance and for the MTF of the HVS.

1.Perceptual Weighting of Errors

Luminance - Brightness
Errors are evaluated on a brightness scale.
Spatial Frequency Weighting
Anisotropic single channel weighting.

2.Perceived Impairments and Distortion Factors

Random Errors - Distortion Factors F1, F2

$$\frac{F_1 \quad \sum_m \sum_n [e_w(m,n)]^2}{\sum_m \sum_n [I(m,n)]^2}$$

$$\frac{F_2 = \sum_m \sum_n [e_w(m,n)]^2 T}{\sum_m \sum_n [I(m,n)]^2}$$

$F1$ and $F2$ use different frequency weighs. T is zero-one indicator of visibility threshold.
Structured Errors - Distortion Factors F3,F4,F5
$F3$= End of Block Errors
End of blocks error discontinuities are horizontal and vertical structures measured by $F3$,
For M N block,

$$F_3 \quad \left[\left[E\left\{ \Delta e_w(iM,n) \right\} \right]^2 + \left[E\left\{ \Delta e_w(m,jN) \right\} \right]^2 \right]^{\frac{1}{2}}$$

$$\Delta e_w(iM,n) \quad e_w(iM,n) \quad e_w(iM+1,n)$$

$$\Delta e_w(m,jN) \quad e_w(m,jN) \quad e_w(m,jN+1$$

$F4$=General correlated errors

structure errors are quantified by their correlation

$$F4 \quad (R_x{}^2 + R_y{}^2)^{\frac{1}{2}}$$

$$R_x \quad \sum_{dm=1}^{M-1} \sum_{k=1}^{N} \left[R\left\{ \frac{e_w(dm,k)}{e_{ox}} \right\} \right]^2$$

$$R_y \quad \sum_{\ell=1}^{M} \sum_{dn=1}^{N-1} \left[R\left\{ \frac{e_w(\ell,dn)}{e_{oy}} \right\} \right]^2$$

$$R\left\{ e_w(dm,k) \right\} \qquad E\left\{ e_w(m+dm,k) \cdot e_w(m,k) \right\}$$

$$R\left\{ e_w(\ell,dn) \right\} \qquad E\left\{ e_w(\ell,n+dn) \cdot e_w(\ell,n) \right\}$$

$$e_{ox} \quad \max\ R\left\{ e_w(0,k) \right\}$$

$$e_{oy} \quad \max\ R\left\{ e_w(\ell,0) \right\}$$

$F5$=Random errors in the vicinity of high contrast image transitions

$$F5 = (e_x{}^2 + e_y{}^2)^{\frac{1}{2}}$$

$$e_x \quad E \quad \sum_{j=-\ell}^{\ell} \left| \, e_w(p+j,\ q)\, S_x(p+j,\ q) \right|$$

$$e_y \quad E \quad \sum_{j=-\ell}^{\ell} \left| \, e_w(p+j,\ q)\, S_y(p+j,\ q) \right| \Big\}$$

and

$$S_x(r,s) = e^{\{-0.04 V_x(r,s)\}}$$

$$S_y(r,s) \quad e^{\{-0.04 V_y(r,s)\}}$$

and $V_x(r,\ s)$ is the horizontal first order difference. Edges are located with a Kirsh operator.

3.Picture Quality Scale(PQS)

The factors $F1$,,,$F5$ are quite correlated.
The largest three eigenvalues amount for 98% of the total error energy.

PQS is a linear combination of distortion factors, or of their principal components $\{Zj\}$.
Only 3 principal components needed.

$$PQS \quad a_o + \sum_{j=1}^{5} aj \cdot Fj$$

or

$$PQS = b_o + \sum_{j=1}^{3} bj \cdot Zj$$

The correlation of PQS versus MOS is quite good at 0.88 for the range of 2 to 4 in MOS.

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Tue Sep 20 00:45:13 PDT 1994

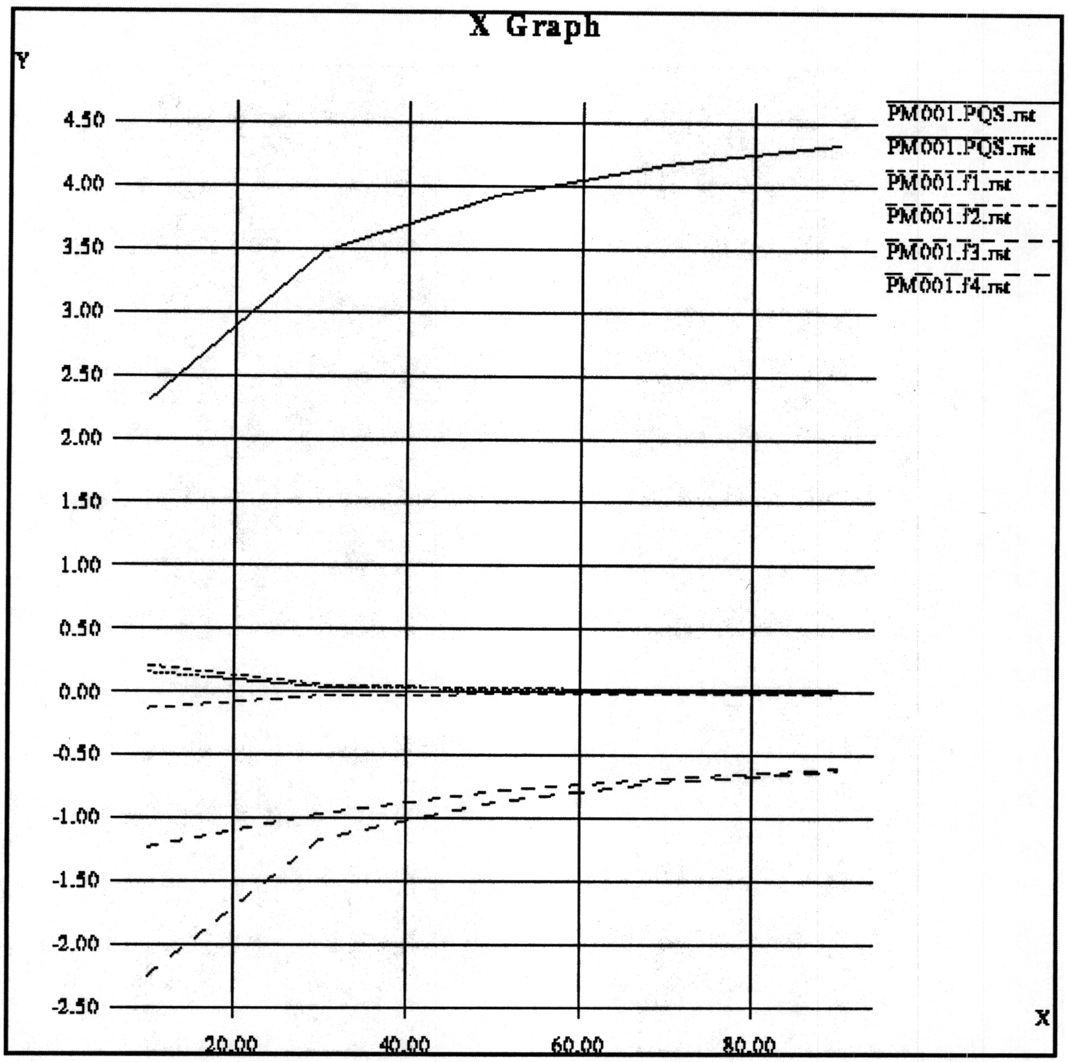
next up previous
Next: PREDICTING VISIBLE DISTORTION **Up:** Important Distortion Factors in **Previous:** THE PQS SYSTEM

IMPORTANT FACTORS AT HIGH QUALITY

- The plot of distortion factors contributions to PQS shows that only F4 and F5 remain significant at high quality.
- We study more closely these factors for high quality images To correlate $F4$ and $F5$ with perceived errors To refine the evaluation of $F4$ and $F5$
- Test image and Coding Scheme

  JPEG compression at Quality level 40
  Four 512 by 512 pixels subimages from one of the NTT 2048 by 2048 pixels images are used for our tests.

- Spatial contributions to $F4$ and $F5$ are shown as grey scale images or distortion maps DM4 and DM5.
- At high quality, only peak values of distortion maps are perceived.



PQS and Distortion Factors VS. JPEG Quality

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next up previous
Next: EXPERIMENTAL RESULTS **Up:** Important Distortion Factors in **Previous:** IMPORTANT FACTORS AT

PREDICTING VISIBLE DISTORTION WITH PQS DISTORTION MAPS

- We examine the ability of spatial distortion maps DM4 and DM5 to predict to the visible coding errors at high quality.
- The histograms of DM4 and DM5 show a large range of values.
- Small values of DM4 and DM5 do not correspond to visible errors.
- With suitable thresholds, DM4 and DM5 are fairly good predictors of perceptible distortion.
- sigmoid functions are used instead of an abrupt threshold
- with

$$sigmoid(x) = e^{a(x-b)}/(e^{a(x-b)} + 1) \cong S(x)$$

We evaluate $DMH4 = S4(x)_{DM4}$ $DMH5 = S5(x)\,DM5$ where $DMH()$ denotes the distortion map at high quality and $S4(x)$ and $S5(x)$ are adjusted experimentally.

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Tue Sep 20 00:45:13 PDT 1994

[x] next [x] up [x] previous
Next: APPLICATIONS OF PQS **Up:** Important Distortion Factors in **Previous:** PREDICTING VISIBLE DISTORTION

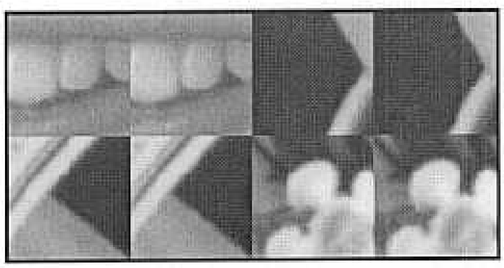
EXPERIMENTAL RESULTS

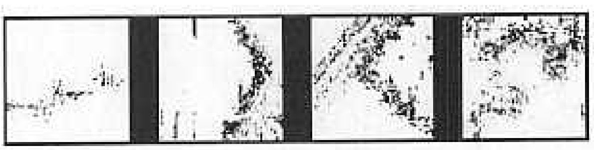
Perceived Errors

- Perceived errors correspond fairly well to image regions indicated by the high quality distortion maps DMH4 and DMH5.
- Only 5 % of the pixels in most images have visible errors.

Distribution of Errors

Distortion maps and images encoded for high quality show that perceptible errors are associated with specific image features
High contrast transitions or edges
High detail regions adjacent to, or on a flat background
Diagonal image structures





We observe the correspondence of distortion maps to perceived coding errors.

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Tue Sep 20 00:45:13 PDT 1994

next up previous
Next: MODIFICATION OF PQS **Up:** Important Distortion Factors in **Previous:** EXPERIMENTAL RESULTS

APPLICATIONS OF PQS

- Comparison of Transforms (DCT), Subband and Wavelet representations.
- Design of quantization matrix for improved performance.
- Optimization of overall coder.
- Example 1: Comparison of Representations.
- Example 2: Optimization of quantization matrix for Wavelet coder,with and without adaptive noise reduction.

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Tue Sep 20 00:45:13 PDT 1994

next up previous

Next: CONCLUSIONS **Up:** Important Distortion Factors in **Previous:** APPLICATIONS OF PQS

MODIFICATION OF PQS AT HIGH QUALITY

- We propose a modification of PQS for high quality that uses only structured errors and modified distortion factors $F4H$ and $F5H$.
- $F4\mathrm{H}$ and $F5\mathrm{H}$ make use of the high quality distortion maps DMH4 and DMH5 with suitable summmation over the entire image.
- Therefore

$$PQS_{\mathrm{H}} \quad a_0 \quad a_1 F_{4\mathrm{H}} \quad a_2 F_{5\mathrm{H}}$$

where the weights $\{a_i\}$ are determined

by fitting the high end of the performance curves.

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Tue Sep 20 00:45:13 PDT 1994

next up previous

Next: Original Image and **Up:** Important Distortion Factors in **Previous:** MODIFICATION OF PQS

CONCLUSIONS

- Study of distortion factors at high quality shows that only structured errors for factors $F4$ and $F5$ are important.
- Experimental study shows that at high quality perceived errors are associated with specific image structures and account only for 5% of the pixels.
- A modified Picture Quality Scale is proposed.
- Examples of applications of PQS are shown.
- Research to be done:
  Relate PQS4H to more complete perceptual models.

  Systematically develop new design strategies and verify results experimentally.

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Tue Sep 20 00:45:13 PDT 1994

next up previous
Next: Combined Distortion Map **Up:** Important Distortion Factors in **Previous:** CONCLUSIONS

Original Image and Encoded Image

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Tue Sep 20 00:45:13 PDT 1994

next up previous
Next: Distortion Map with **Up:** Important Distortion Factors in **Previous:** Original Image and

Combined Distortion Map (DM4 , DM5)

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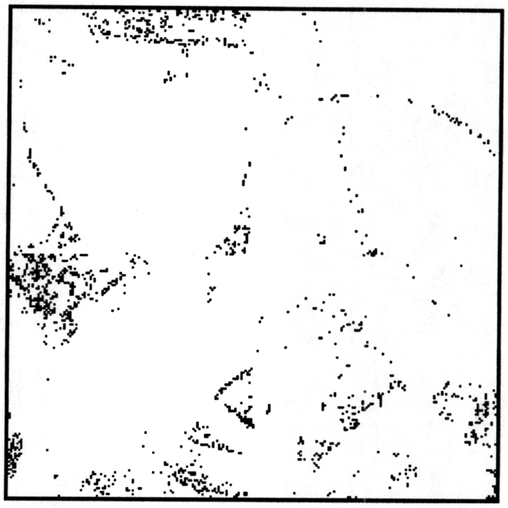
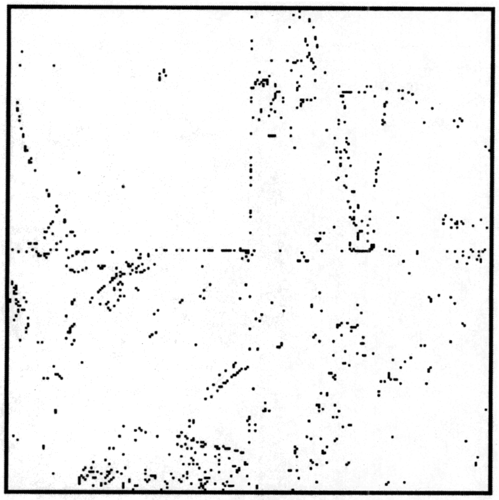
Tue Sep 20 00:45:13 PDT 1994

next up previous
Next: Image Feature Used **Up:** Important Distortion Factors in **Previous:** Combined Distortion Map

Distortion Map with Threshold(DM4, DM5





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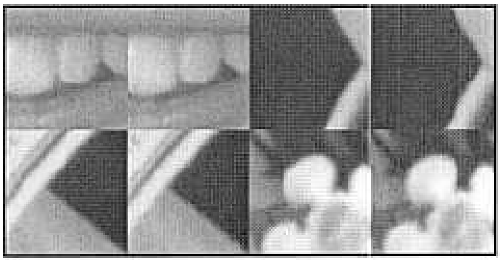
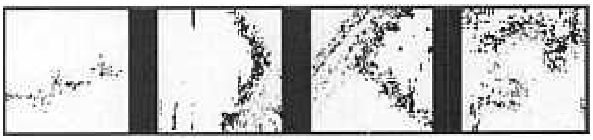
Tue Sep 20 00:45:13 PDT 1994

Image Feature Used in the Experiments





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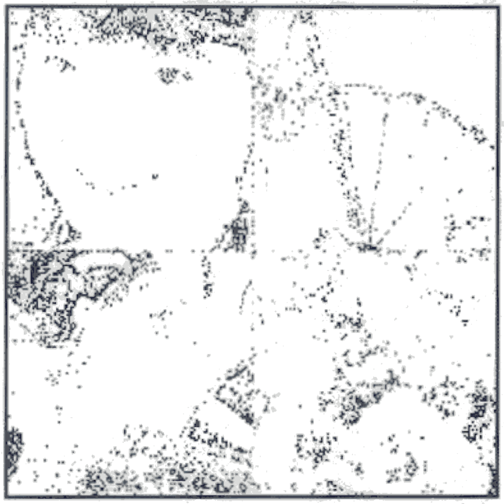
[x] next [x] up [x] previous

Next: About this document **Up:** Important Distortion Factors in **Previous:** Image Feature Used

Combined Distortion Map with Sigmoid



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