Rate-distortion performance evaluation of JPEG-XR

Objective results and proposed methodology for subjective quality assessment

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Outline of the presentation

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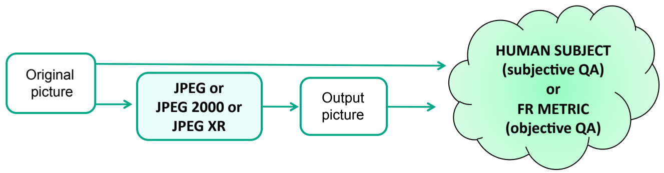
  - Test conditions
  - Preliminary results

Introduction

- **Quality Assessment (QA) and codec performance evaluation**
- **Status**
- **Our previous contributions**

QA and codec performance evaluation

- Codec performance evaluation in terms of:
  - Compression efficiency.
  - Computational requirements.
  - Additional functionalities.
- Rate-Distortion (RD) curves = quality measure vs bit per pixel



Status

THERE ARE NOT YET RELIABLE and STANDARD OBJECTIVE METHODS FOR IMAGE QUALITY ASSESSMENT

- Image and video systems complexity
- Human Visual System (HVS) complexity
- Lack of standardization

➢ ***Objective QA** can be performed to provide a **first comparison of a wide range of conditions.***

➢ ***Subjective QA** needs to be performed as **benchmark, to validate the results of the objective metrics.***

Our previous contributions

JPEG contributions:

- F. De Simone et al., **"Comparison of PSNR performance of HD Photo and JPEG2000"**, wg1n4404, JPEG meeting Kobe (Nov. 2007)
- F. De Simone et al., **"Objective evaluation of the rate-distortion performance of JPEG-XR"**, wg1n4552, JPEG Interim meeting Poitiers (Feb. 2008)
- F. De Simone et al., **"Still image coding algorithms performance comparison: objective quality metrics"**, wg1n4497, JPEG meeting San Francisco (Apr. 2008)
- F. De Simone et al., **"Objective rate-distortion performance of different JPEG-XR implementations"**, wg1n4701, JPEG meeting Poitiers (July 2008)

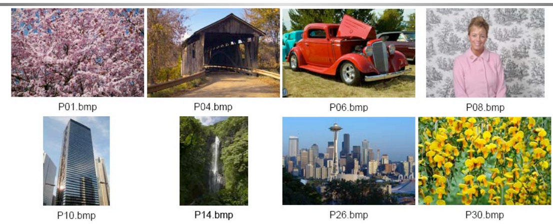
Conference publications:

- F. De Simone et al., **"A comparative study of JPEG 2000, AVC/H.264, and HD Photo"**, SPIE Optics and Photonics, Applications of Digital Image Processing XXX, 6696 (Aug. 2007)
- F. De Simone et al., **"A comparative study of color image compression standards using perceptually driven quality metrics"**, SPIE Optics and Photonics, Applications of Digital Image Processing XXXI (Aug. 2008)

Objective QA

- **Test material**
- **Codecs and configuration parameters**
- **Quality metrics**
- **Selected results**

Test Material – 24 bpp pictures



(sample pictures from Microsoft dataset,
6 different spatial resolutions: 4064x2704, 2268x1512, 2592x1944, 2128x2832, 2704x3499, 4288x2848)

(sample pictures from Thomas Richter dataset,
2 different spatial resolutions: 3888x2592, 2592x3888)

Codecs and configuration parameters

JPEG XR vs JPEG2000 vs JPEG:

- **JPEG XR (DPK version 1.0):**
  - one level overlapping and two level overlapping.
  - 4:4:4 and 4:2:0 chroma subsampling.
- **JPEG 2000 (Kakadu version 6.0):**
  - default settings (64x64 code-block size, 1 quality layer, no precincts, 1 tile, 9x7 wavelet, 5 decomposition levels).
  - rate control.
  - no visual frequency weighting and visual frequency weighting.
  - 4:4:4 and 4:2:0 chroma subsampling.
- **JPEG (IJG version 6b):**
  - default settings (Huffman coding).
  - default visually optimized quantization tables.
  - 4:4:4 and 4:2:0 chroma subsampling.

Codecs and configuration parameters

Different JPEG XR implementations:

- **JPEG XR DPK version 1.0:**
  - different quantization steps for different color channels (default).
  - same quantization steps for different frequency bands (default).
- **JPEG XR Reference Software version 1.0:**
  - same quantization steps for different color channels (default).
  - same quantization steps for different frequency bands (default).
- **JPEG XR Reference Software version 1.2 - i.e. Thomas Richter's version:**
  - different quantization steps for different color channels (same as DPK).
  - different quantization steps for different frequency bands (default).
  - new POT (leakage fix described in wg1n4660) (default).
- **JPEG XR Microsoft implementation described in HDPn21 / wg1n4549 :**
  - different quantization steps for different color channels (enhanced encoding techniques
  - described in HDPn21 / wg1n4549) (default).
  - different quantization steps for different frequency bands (enhanced encoding techniques of HDPn21 / wg1n4549) (default).
  - new POT (leakage fix described in wg1n4660) (default).

Metric 1: Maximum Pixel Deviation (L_{inf})

- Considering RGB color space:

$$L_{inf\,R} = \max\left[\mathrm{abs}(Im_{aR}(x,y) - Im_{bR}(x,y))\right]$$
$$L_{inf\,G} = \max\left[\mathrm{abs}(Im_{aG}(x,y) - Im_{bG}(x,y))\right]$$
$$L_{inf\,B} = \max\left[\mathrm{abs}(Im_{aB}(x,y) - Im_{bB}(x,y))\right]$$

$(L_{inf} \in [0,1])$

where:

Im_a, Im_b = pictures to compare

Metric 2: single channel PSNR

$$\boxed{PSNR = 10\log_{10}\frac{(2^B-1)^2}{MSE}}$$

where: $MSE = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}[Im_a(x,y) - Im_b(x,y)]^2$

M, N = image dimensions

Im_a, Im_b = pictures to compare

B= bit depth

- PSNR evaluation considering:
  - R, G and B components
  - Y', C_b and C_r components (ITU-R Rec. BT.601)

Metric 3: PSNR weighted average (WPSNR)

- PSNR considering weighted summation of the PSNRs evaluated on R, G and B components or Y’, Cb and Cr components (ITU-R Rec. BT. 601):

$$\boxed{WPSNR = w_1 PSNR_1 + w_2 PSNR_2 + w_3 PSNR_3}$$

where:

$w_1 = 1/3,\ w_2 = 1/3,\ w_3 = 1/3$ considering R,G, and B components.

$w_1 = 0.8,\ w_2 = 0.1,\ w_3 = 0.1$, considering Y’, C_b, and C_r components.

Metric 3: PSNR weighted average (WPSNR_MSE)

- PSNR considering weighted summation of the MSEs evaluated on R, G and B components or Y’, Cb and Cr components (ITU-R Rec. BT. 601):

$$\boxed{WPSNR\_MSE = 10\log_{10} \frac{(2^B - 1)^2}{(w_1 MSE_1 + w_2 MSE_2 + w_3 MSE_3)}}$$

where:

$w_1 = 1/3,\ w_2 = 1/3,\ w_3 = 1/3$ considering R,G, and B components.

$w_1 = 0.8,\ w_2 = 0.1,\ w_3 = 0.1$, considering Y’, C_b, and C_r components.

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Metric 3: PSNR weighted average (WPSNR_PIX)

- PSNR considering MSE evaluated on weighted summation of the image R, G and B components:

$$\boxed{WPSNR\_PIX = 10\log_{10} \frac{(2^B - 1)^2}{\frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}\left[\left(w_1 Im_{a1}(x,y) + w_2 Im_{a2}(x,y) + w_3 Im_{a3}(x,y)\right) - \left(w_1 Im_{b1}(x,y) + w_2 Im_{b2}(x,y) + w_3 Im_{b3}(x,y)\right)\right]^2}}$$

where:

M, N = image dimensions

Im_a, Im_b = pictures to compare

B= bit depth

$w_1 = 1/3,\ w_2 = 1/3,\ w_3 = 1/3$ considering R,G, and B components.

$w_1 = 0.8,\ w_2 = 0.1,\ w_3 = 0.1$, considering Y’, Cb, and Cr components.

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Metric 4: Mean SSIM (MSSIM) (I)

[1] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, “Image Quality Assessment: From Error Measurement to Structural Similarity” (2004).

- Structural information = “attributes that represent the structure of objects in the scene, independent of the average luminance and contrast”.

➢ Estimate of luminance = mean intensity: $\mu = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N} Im(x,y)$

➢ Estimate of contrast = standard deviation: $\sigma = \left(\frac{1}{MN-1}\sum_{y=1}^{M}\sum_{x=1}^{N}(Im(x,y)-\mu)^2\right)^{1/2}$

➢ Estimate of picture structure: $\frac{(Im - \mu)}{\sigma}$

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Metric 4: Mean SSIM (MSSIM) (II)

$$\mathrm{SSIM}(\mathrm{Im}_1,\mathrm{Im}_2) = \left[l(\mathrm{Im}_1,\mathrm{Im}_2)\right]^{\alpha}\left[c(\mathrm{Im}_1,\mathrm{Im}_2)\right]^{\beta}\left[s(\mathrm{Im}_1,\mathrm{Im}_2)\right]^{\gamma} \quad (\alpha>0,\beta>0,\gamma>0)$$

- **Luminance comparison function:** $l(\mathrm{Im}_1,\mathrm{Im}_2) = \dfrac{2\mu_1\mu_2 + C_1}{\mu_1^2+\mu_2^2+C_1}$ (C_1=constant)
- **Contrast comparison function:** $c(\mathrm{Im}_1,\mathrm{Im}_2) = \dfrac{2\sigma_1\sigma_2 + C_2}{\sigma_1^2+\sigma_2^2+C_2}$ (C_2=constant)
- Measure of structural similarity = correlation between $\dfrac{(\mathrm{Im}_1-\mu_1)}{\sigma_1}$ and $\dfrac{(\mathrm{Im}_2-\mu_2)}{\sigma_2}$

Structure comparison function: $s(\mathrm{Im}_1,\mathrm{Im}_2) = \dfrac{\sigma_{1,2} + C_3}{\sigma_1\sigma_2+C_3}$ (C_3=constant)

where $\sigma_{1,2} = \dfrac{1}{MN-1}\sum_{y=1}^{M}\sum_{x=1}^{N}(\mathrm{Im}_1(x,y)-\mu_1)(\mathrm{Im}_2(x,y)-\mu_2)$

Metric 4: Mean SSIM (MSSIM) (III)

- The SSIM indexing algorithm is applied using a sliding window approach which results in a SSIM index quality map of the image.
- The average of the quality map is called **Mean SSIM index (MSSIM)**.
- Weighted summation of MSSIM indexes evaluated on Y', Cb and Cr components (Y'CbCr color space - Rec. ITU-R BT.601):

$$\boxed{\mathrm{MSSIM} = w_y \mathrm{MSSIM}_Y + w_{Cb}\mathrm{MSSIM}_{Cb} + w_{Cr}\mathrm{MSSIM}_{Cr}} \quad (\mathrm{MSSIM} \in [0,1])$$

where: $w_Y = 0.8,\ w_{Cb} = 0.1,\ w_{Cr} = 0.1.$

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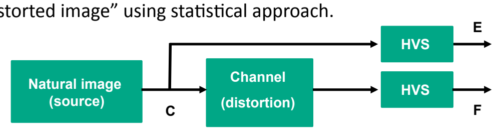
Metric 5: Visual Information Fidelity – Pixel (VIF-P) (I)

[2] H. R. Sheikh, A. C. Bovik "Image Information And Visual Quality" (2004).

- "Image information measure that quantifies the information that is present in the reference image and how much this reference information can be extracted from the distorted image" using statistical approach.



- Reference image (E) = output of a stochastic natural source that passes through HVS channel and is processed by the brain
- Test image (F) = output of an image distortion channel that distorts the output of the natural source before it passes through the HVS channel

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Metric 5: Visual Information Fidelity – Pixel (VIF-P) (II)

- Natural image modeling in wavelet domain using Gaussian scale mixtures (GSMs)
- **Information that the brain could ideally extract from reference image** = mutual information between C and E: $I(C;E|z)$
- **Corresponding information that could be extracted from test image** = mutual information between C and F: $I(C;F|z)$

$$\mathrm{VIF} = \frac{I(C,F|z)}{I(C,E|z)}$$

(VIF $\in [0,1]$ and VIF>1 if the test image is enhanced version of the original)

where:

z= source model parameters.

- **VIF-P** is a new implementation in a multi-scale pixel domain:
  - computationally simpler than Wavelet domain version.
  - performance slightly worse than Wavelet domain version.

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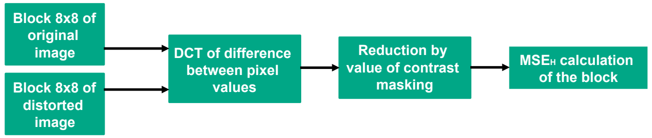
Metric 6: PSNR-HVS-M (I)

[3] N. Ponomarenko, F. Silvestri, K. Egiazarian, M.Carli, J. Astola, and V. Lukin, “On between-coefficient contrast masking of DCT basis functions” (2007).



- DCT coefficients of 8x8 pixel blocks X and Y are visually undistinguished if:

  $E_w(X-Y) < \max(E_m(X), E_m(Y))$

  where E_w(block) is the energy of DCT coefficients of the block weighted according to CSF and E_m(block) is the masking effect of DCT coefficients of the block which depends upon E_w(block) and upon the local variances.

Metric 6: PSNR-HVS-M (II)

$$\boxed{PSNR-HVS-M = 10\log_{10}\frac{(2^B-1)^2}{MSE_H}}$$

where: $$MSE_H = K\sum_{i=1}^{M-7}\sum_{j=1}^{N-7}\sum_{m=1}^{8}\sum_{n=1}^{8}\left[X(m,n)_{\Delta ij}\,T_c(m,n)\right]^2$$

M, N = image dimensions

K= constant

$X(m,n)_{\Delta ij}$ = visible difference between DCT coefficient of the original image and distorted image 8x8 blocks, depending upon contrast masking

T_c = matrix of correcting factors based on standard visually optimized JPEG quantization tables

B= bit depth

Metric 7: DC Tune

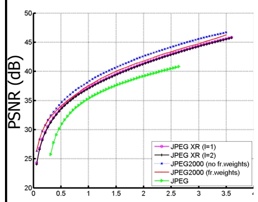
[4] A. B. Watson, A. P. Gale, J. A. Solomon, and A. J. Ahumada JR., “DCTune: A Techinque For Visual Optimization Of DCT Quantization Matrices For Individual Images” (1994).

- developed as a method for optimizing JPEG image compression by computing the JPEG quantization matrices which yields a designated perceptual error
- model of perceptual error based upon DCT coefficients analysis, taking into account:
  - luminance masking.
  - contrast masking.
  - spatial error pooling.
  - frequency error pooling.

Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

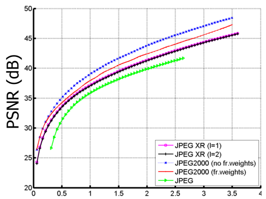
Average over image dataset of PSNR values

on R component:



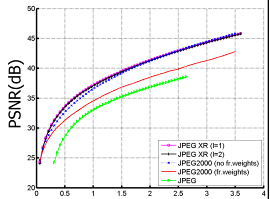
bpp (bits/pixel)

on G component:



bpp (bits/pixel)

on B component:

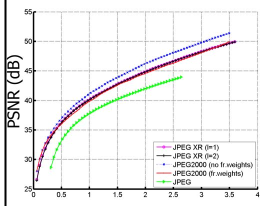


bpp (bits/pixel)

Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

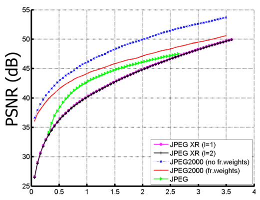
Average over image dataset of PSNR values

on Y’ component:



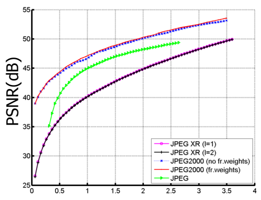
bpp (bits/pixel)

on Cb component:



bpp (bits/pixel)

on Cr component:

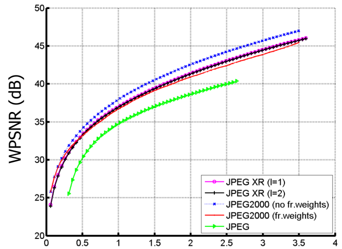


bpp (bits/pixel)

Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

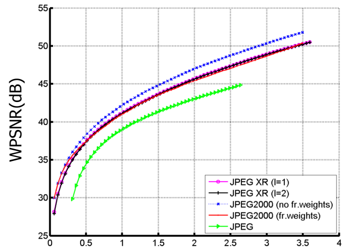
Average over image dataset of WPSNR values

on RGB components:



bpp (bits/pixel)

on Y’CbCr components:

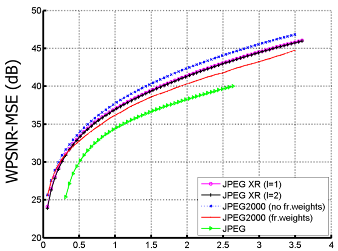


bpp (bits/pixel)

Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

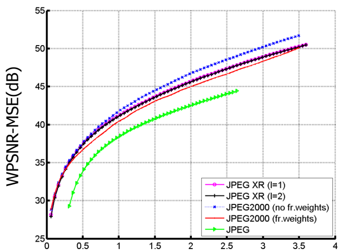
Average over image dataset of WPSNR-MSE values

on RGB components:



bpp (bits/pixel)

on Y’CbCr components:

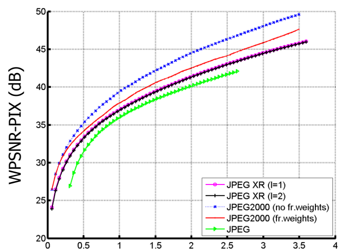


bpp (bits/pixel)

Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

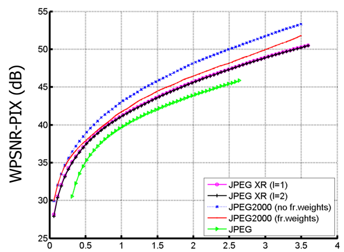
Average over image dataset of WPSNR-PIX values

on RGB components:



bpp (bits/pixel)

on Y’CbCr components:

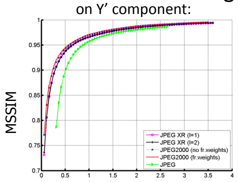


bpp (bits/pixel)

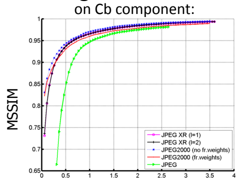
Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

Average over image dataset of MSSIM values

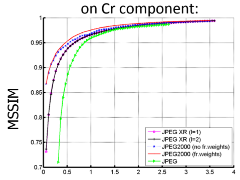
on Y’ component:

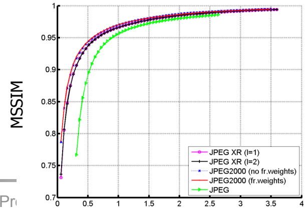


on Cb component:



on Cr component:



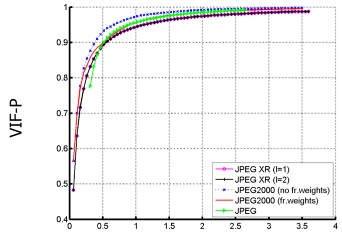


bpp (bits/pixel)

Selected results 4:4:4 – JPEG XR vs JPEG2000 vs JPEG

Average over image dataset of VIF-P values

on Y’ component only:



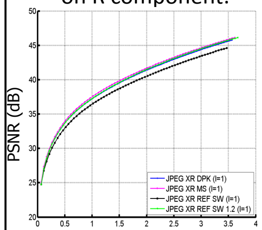
bpp (bits/pixel)

Selected results 4:4:4 – different JPEG XR implem.

Average over image dataset of PSNR values

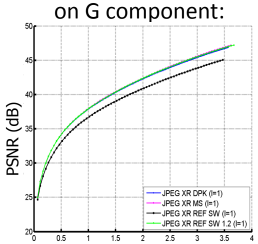
(one level POT)

on R component:



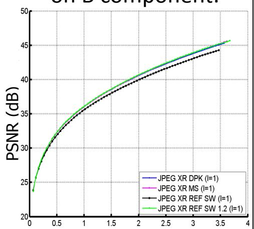
bpp (bits/pixel)

on G component:



bpp (bits/pixel)

on B component:



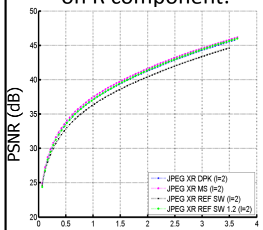
bpp (bits/pixel)

Selected results 4:4:4 – different JPEG XR implem.

Average over image dataset of PSNR values

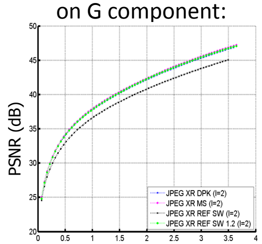
(two levels POT)

on R component:



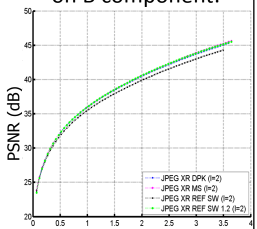
bpp (bits/pixel)

on G component:



bpp (bits/pixel)

on B component:



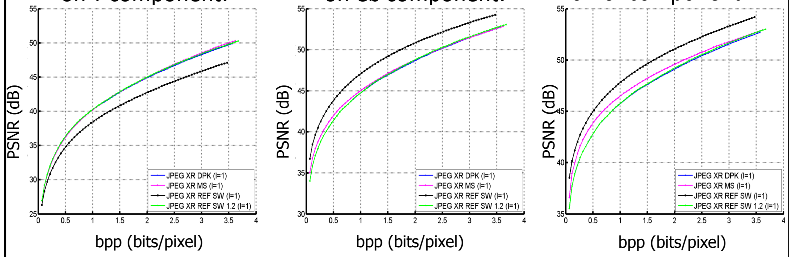
bpp (bits/pixel)

Selected results 4:4:4 – different JPEG XR implem. 33

Average over image dataset of PSNR values

(one level POT)

on Y component: on Cb component: on Cr component:

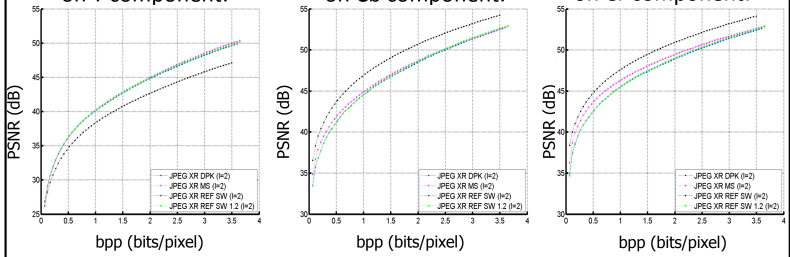


Selected results 4:4:4 – different JPEG XR implem. 34

Average over image dataset of PSNR values

(two levels POT)

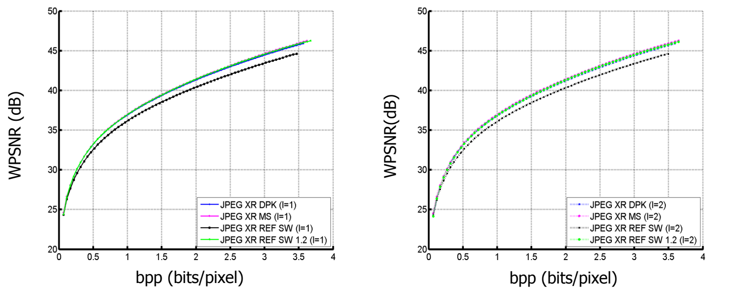
on Y component: on Cb component: on Cr component:



Selected results 4:4:4 – different JPEG XR implem. 35

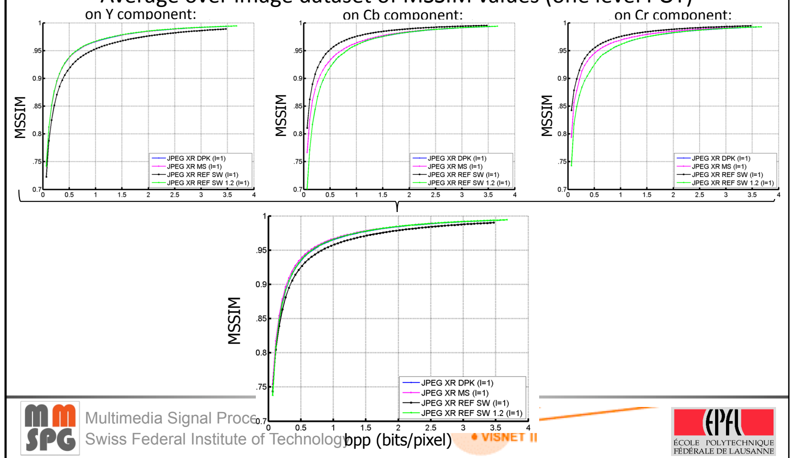
Average over image dataset of WPSNR_MSE values

one level POT: two levels POT:



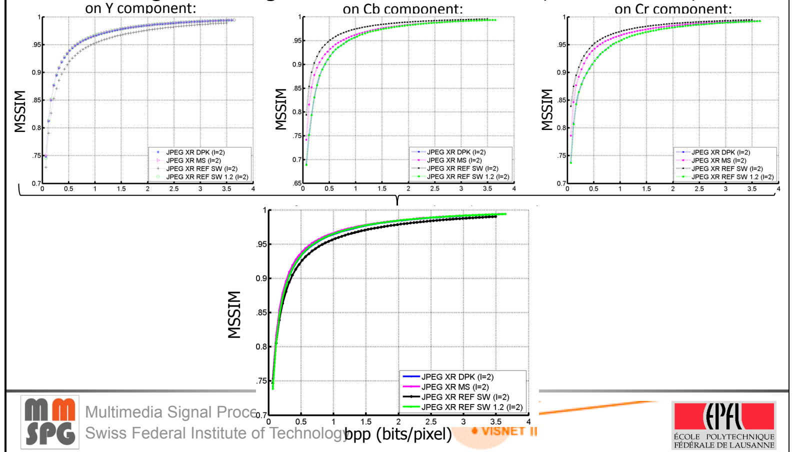
Selected results 4:4:4 – different JPEG XR implem. 36

Average over image dataset of MSSIM values (one level POT)



Selected results 4:4:4 – different JPEG XR implem.

Average over image dataset of MSSIM values (two levels POT)



Subjective QA

- **Proposed methodology**
- **Test conditions**
- **Preliminary results**

Proposed methodology (I)

- **Double Stimulus Continuous Quality Scale (DSCQS) method** [ITU-R Rec. BT.500-11] adapted to deal with the evaluation of still pictures:

Reference Image

Test Image

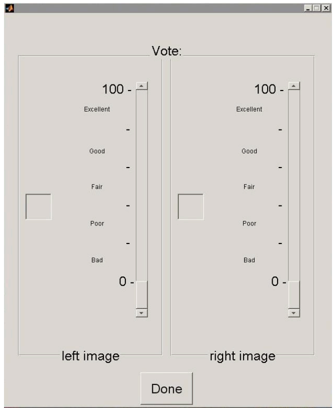
- test picture and its reference are shown at the same time.
- the assessor is not told about the presence of a reference picture.
- positions of reference and test pictures are systematically switched.
- test pairs related to different original contents are always alternated.

Proposed methodology (II)

- when the subject clicks into the active area of the screen a rating window is shown:

Proposed methodology (III)

Rating window
(Continuous Quality Scale)



- the subject has to rate the quality of the two pictures choosing for each a value in between 0 (worse quality possible) to 100 (best quality possible).

Proposed methodology (IV)

- Subjects are checked for visual acuity and color blindness
- Before each session, instructions are provided to subjects and a **training session** is performed to explain how to use the rating scale
  - *contents shown for training are not used for testing*
  - *data gathered during the training are not included in the final test results*
- Some **dummy presentations** are inserted at the beginning of the test to stabilize subject's behaviour
  - *data gathered from the dummies are not included in the final test results*
  - *the dummy presentations cover all the quality levels included in the test material*
- The test session lasts **no more than 20 minutes (including training)**

Proposed methodology (V)

- At least 15 subjects
- Subjective data processing:
  - *computation of **Differential Score (DS)**:*
    DS = Score for the reference picture – Score for the test picture
  - ***ANalysis Of Variance (ANOVA)** to detect eventual systematic errors and **scores normalization** to remove them*
  - ***screening** to detect outliers* [ITU-R Rec. BT.500-11]
  - *computation of the **Differential Mean Opinion Score (DMOS)***

Test conditions

- Eizo CG301W LCD monitor (2560x1600 pixels)
- monitor calibration using color calibration device (EyeOne Display2)
  - Gamut sRGB, white point D65, brightness 120cd/m2, minimum black level.
- controlled lighting system: neon lamps with 6500 K color temperature
- ambient light measurement by EyeOne Display2 tool

Preliminary results (I)

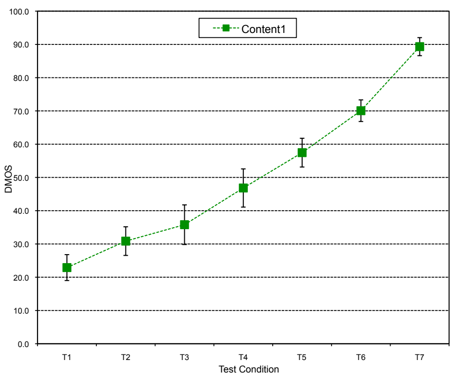
- JPEG XR Microsoft implementation described in HDPn21:
  - different quantization steps for different color channels (enhanced encoding techniques described in HDPn21 / wg1n4549) (default)
  - different quantization steps for different frequency bands (enhanced encoding techniques of HDPn21 / wg1n4549) (default)
  - new POT (leakage fix described in wg1n4660) (default)
- 4:4:4 coding, one level POT
- 4 contents, 7 selected samples corresponding to the following bpp values:

Content	q=40 (T1)	q=50 (T2)	q=58 (T3)	q=66 (T4)	q=76 (T5)	q=82 (T6)	q=90 (T7)
Cont. 1	0.9	0.64	0.46	0.34	0.22	0.18	0.13
Cont. 2	0.15	0.1	0.07	0.05	0.04	0.03	0.02
Cont. 3	0.9	0.61	0.43	0.31	0.19	0.15	0.1
Cont. 4	0.65	0.44	0.31	0.22	0.13	0.09	0.06

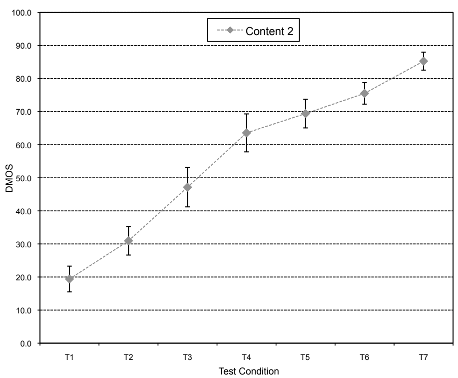
Preliminary results (II)

- 2 contents, other than those used in the test session, have been used for the training session
- 17 subjects have taken part to the experiment:
  - 3 females, 14 males
  - average subject's age 29
- Statistical analysis of the data:
  - inter-subjects ANOVA
  - offset and gain score normalization
  - outliers' screening:
    - 4 outliers for content 1
    - 2 outliers for content 2
    - 2 outliers for content 3
    - 5 outliers for content 4

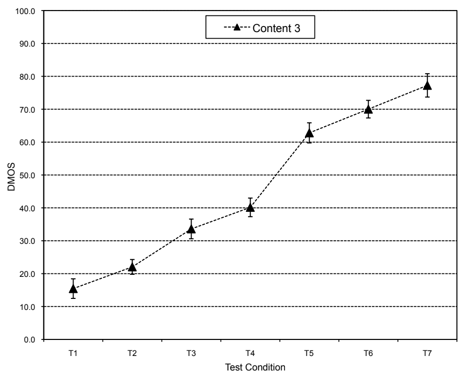
Preliminary results (III)



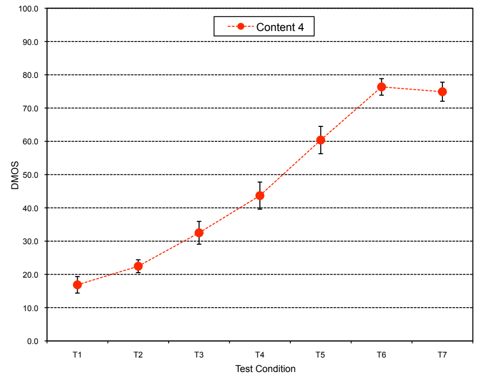
Preliminary results (IV)



Preliminary results (V)



Preliminary results (VI)



Acknowledgement

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Thank you for your attention! Questions?