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Département de génie logiciel et des TI

A NOVEL APPROACH FOR COMPUTING AND POOLING STRUCTURAL SIMILARITY INDEX IN THE DISCRETE WAVELET DOMAIN

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AGENDA

1. **Introduction to Structural SIMilarity**
   - Structural SIMilarity (SSIM) Index
   - Multi-scale & Multi-level SSIM
2. **The Proposed Method**
   - Description of the Proposed Framework
   - Computational Complexity of the Algorithm
3. **Experimental Results**
4. **Conclusion**

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1. Introduction to Structural SIMilarity

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Full-Reference Image Quality Metrics

- **PSNR:**

$$\text{PSNR} = 10 log_{10} \frac{L^2}{\frac{1}{\text{N}} \sum_{m,n} \left(X(m,n) - Y(m,n) \right)^2} = 10 log_{10} \frac{L^2}{\text{MSE}}$$

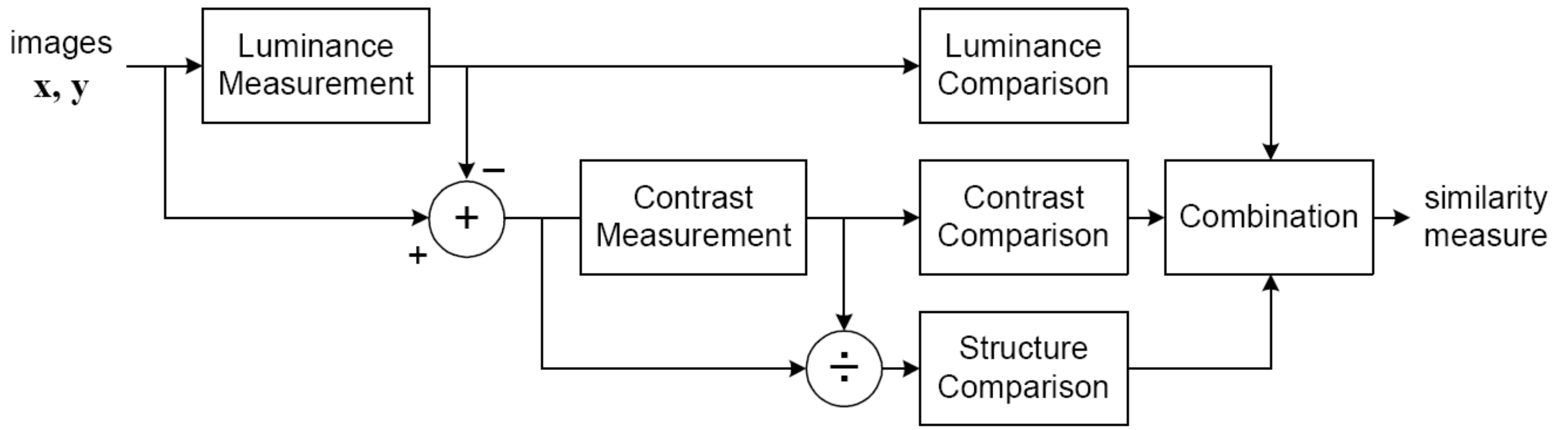
  - PSNR (MSE) is simple and has a clear physical meaning
  - PSNR does not accurately reflect the perceived image/video quality
  - A large gain in PSNR may result in a small improvement in visual quality

- **Structural SIMilarity (SSIM) Index [wang2004*]**

  - HVS is highly adapted to extract structural information from visual scenes
  - Structural similarity/distortion provides a good approximation of the perceptual quality
  - SSIM is mimicking the hypothesized functionality of the overall HVS

* Authors: Z. Wang, A.C. Bovik, H.R. Sheikh and E.P. Simoncelli

Structural SIMilatity (SSIM) Index



$$\mathrm{SSIM}(\mathbf{x},\mathbf{y}) = l(\mathbf{x},\mathbf{y})\cdot c(\mathbf{x},\mathbf{y})\cdot s(\mathbf{x},\mathbf{y}) = \left(\frac{2\mu_x\mu_y + C_1}{\mu_x^2+\mu_y^2+C_1}\right)\cdot\left(\frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2+\sigma_y^2+C_2}\right)\cdot\left(\frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y+C_3}\right)$$

- SSIM properties:
- Symmetry SSIM(**x**,**y**) = SSIM(**y**,**x**)
- Boundedness: SSIM(**x**,**y**) ≤ 1
- Relatively accurate prediction: better than PSNR
- Good trade-off between accuracy and complexity

Multi-scale & Multi-level SSIM

- **Multi-scale SSIM:**
  - incorporating image details at different resolutions by successive low-pass filtering
- **Multi-level SSIM**
  - Five-level decomposition using the Daubechies 9/7 wavelet
  - weighted mean of all SSIMs between corresponding subbands
- **Disadvantages:**
  - Finding the sensitivity of the HVS to different scales or subbands requires many experiments
    - effective combining of several subbands scores is also difficult
  - Multi-level decomposition of images makes the size of the approximation subband very small
    - no longer effective extraction of image statistics
  - Mean of the SSIM map is used in previous methods
    - various image areas have different impacts on the HVS

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2. The Proposed Method

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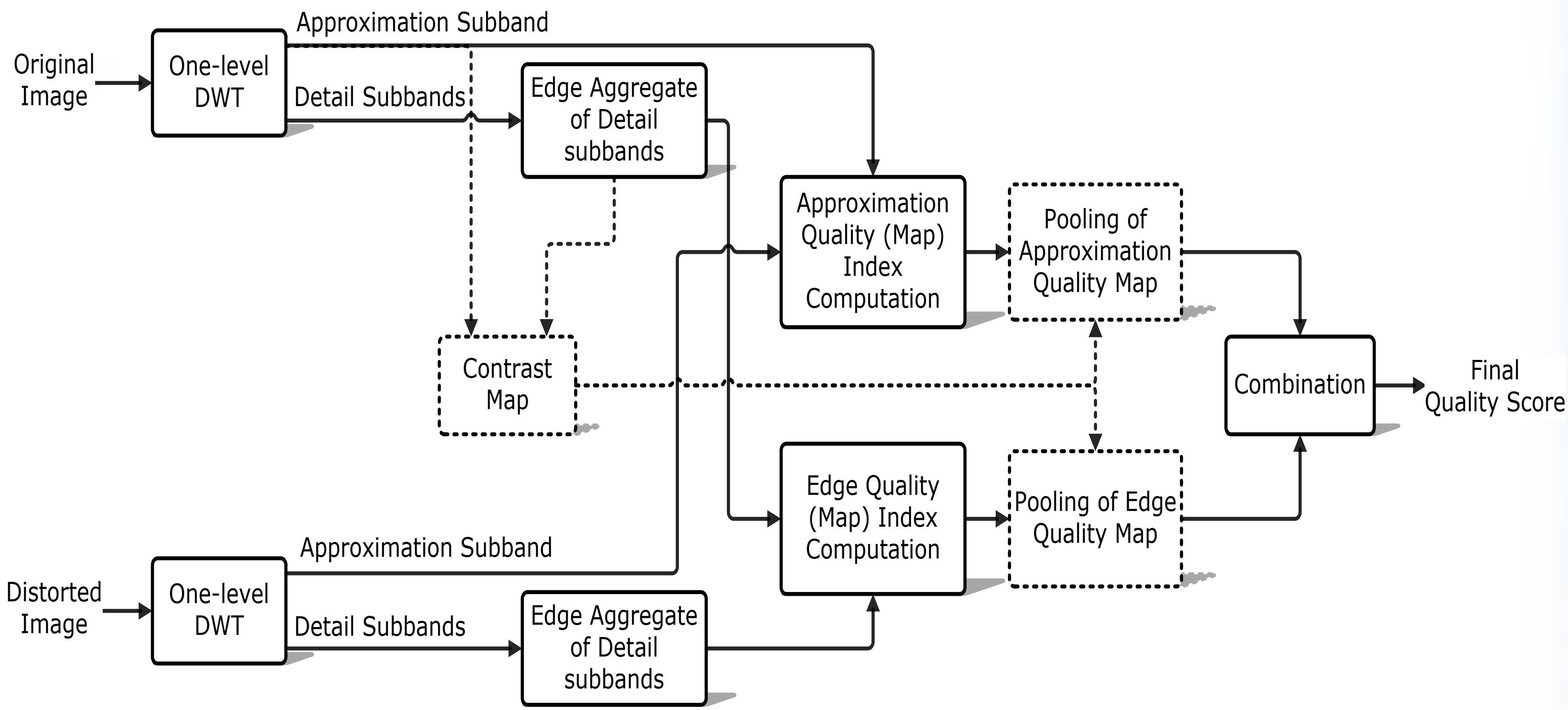
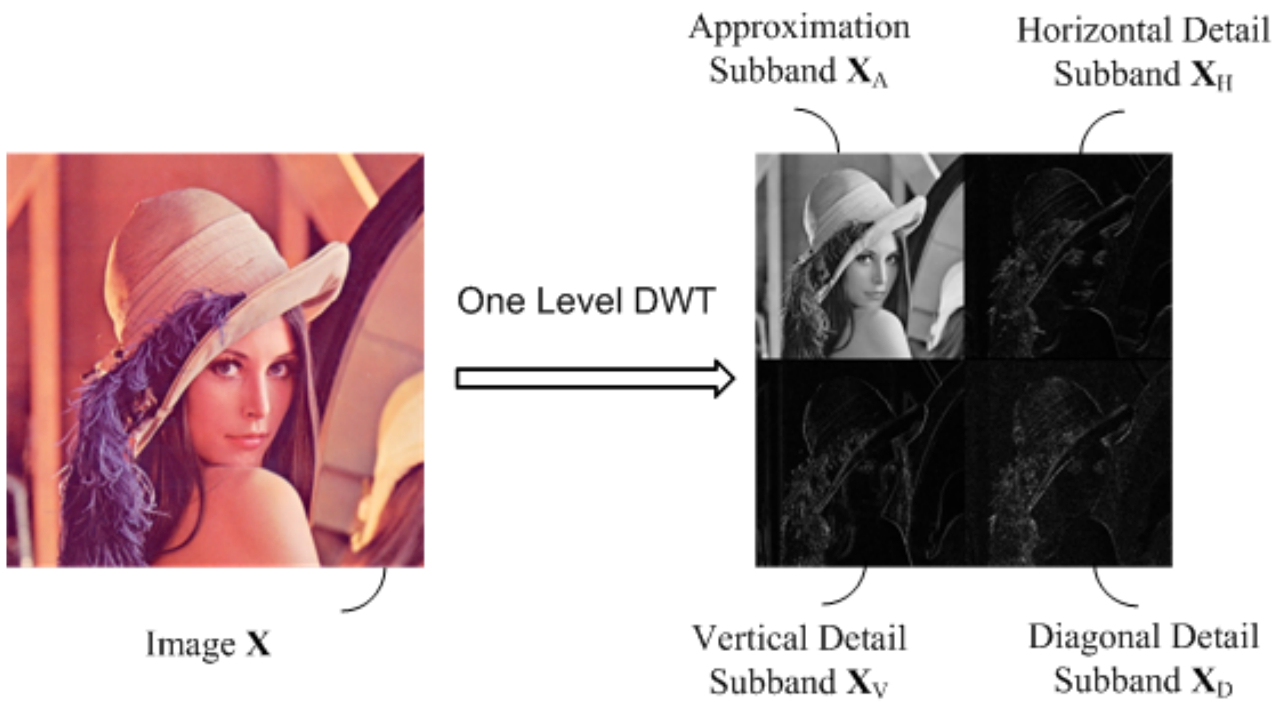
The Proposed Framework



The Proposed Quality Metric

- With proposed framework, we can compute wavelet structural similarity
  - Excellent trade-off between complexity and accuracy
  - Computation performed in the discrete wavelet domain
    - Haar basis is used because of simplicity and symmetry



Edge Maps Computation and Comparison

- **Edge-map functions:**
  - mean square of detail subbands

$$\mathbf{X}_{\mathrm{E}}(m,n) = \frac{\mathbf{X}_{\mathrm{H}}^{2}(m,n) + \mathbf{X}_{\mathrm{V}}^{2}(m,n) + \mathbf{X}_{\mathrm{D}}^{2}(m,n)}{3}$$

$$\mathbf{Y}_{\mathrm{E}}(m,n) = \frac{\mathbf{Y}_{\mathrm{H}}^{2}(m,n) + \mathbf{Y}_{\mathrm{V}}^{2}(m,n) + \mathbf{Y}_{\mathrm{D}}^{2}(m,n)}{3}$$

  - only form image-edge structures and contain no luminance information

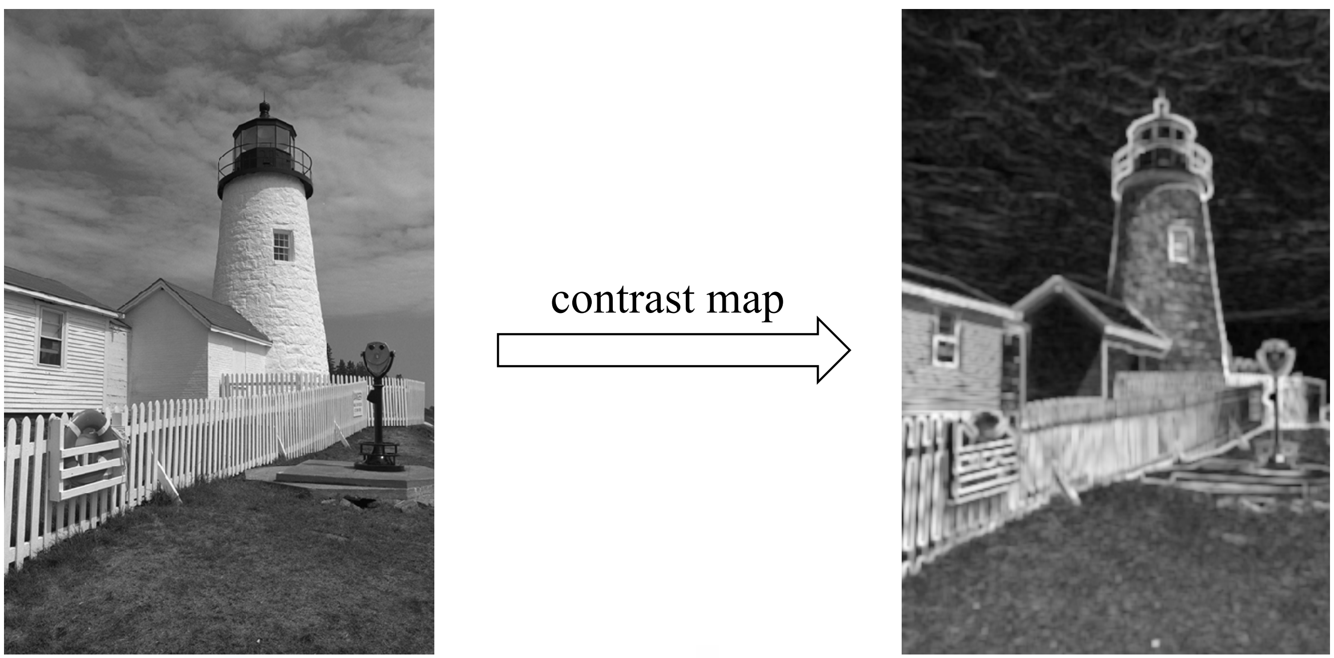
$$\mathrm{SSIM}_{\mathrm{E}}(\mathbf{x}_{\mathrm{E}}, \mathbf{y}_{\mathrm{E}}) = \frac{2\sigma_{x_{\mathrm{E}}, y_{\mathrm{E}}} + c}{\sigma_{x_{\mathrm{E}}}^{2} + \sigma_{y_{\mathrm{E}}}^{2} + c}$$

  - forming contrast map function for pooling

$$Contrast(\mathbf{x}_{\mathrm{E}}, \mathbf{x}_{A}) = (\mu_{x_{\mathrm{E}}} \sigma_{x_{A}}^{2})^{0.1}$$

The Contrast Map

- A novel contrast map for discrete wavelet domain pooling
  - Pixels near edges are given more importance
  - High energy regions are likely to contain more information
  - Brighter sample values in the contrast map indicate more important image structures



Final Quality Score Computation

- **Weighted pooling of approximation and edge maps**
  - for approximation map

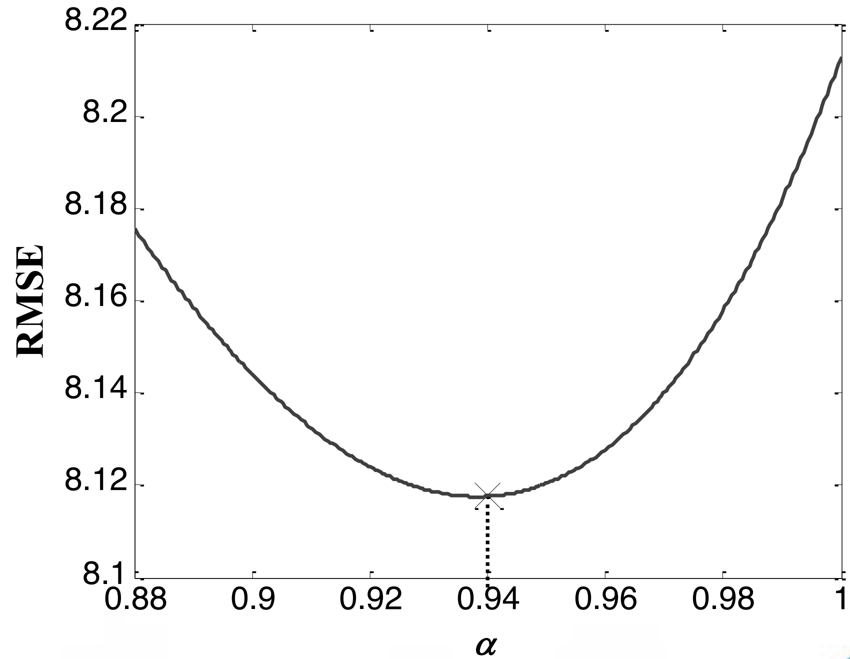
$$S_A = \frac{\sum_{j=1}^{M} Contrast(\mathbf{x}_{E,j}, \mathbf{x}_{A,j}) \cdot \mathrm{SSIM}_A(\mathbf{x}_{A,j}, \mathbf{y}_{A,j})}{\sum_{j=1}^{M} Contrast(\mathbf{x}_{E,j}, \mathbf{x}_{A,j})}$$

  - Pooling of edge map is similar to approximation map

- **Final quality score**

$$WSSI(\mathbf{X}, \mathbf{Y}) = \alpha S_A + (1-\alpha) S_E$$

$$0 < \alpha \leq 1$$



Computational Complexity of the Algorithm

- The algorithm provides excellent trade-off between accuracy and complexity
  - resolution of the approximation subband and edge map is a quarter of that of the original image
  - accurate local statistics can be extracted with a small sliding window size of 4×4.
  - Discrete wavelet transform has fast implementation
    - a simple wavelet (Haar wavelet) is used to reduce complexity
  - local statistics calculated for approximation and edge maps are used to form the contrast map.
    - no new parameters are needed for obtaining contrast map
  - luminance comparison part in the approximation SSIM map can be ignored (just 0.03% reduction in accuracy)
- The running time for calculating the WSSI is, on average, about 0.65 of running time for spatial domain SSIM

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3. Experimental Results

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Simulation Results

- Performance evaluation carried out on LIVE Image Quality Assessment Database Release 2
  - 779 distorted images and 5 types of distortions
    - JPEG, JPEG2000, white noise, Gaussian blurring, fast fading channel model
- Three performance measures adopted
  - Correlation coefficients (CC) for prediction accuracy
  - Root mean square error (RMSE) for prediction consistency
  - Spearman rank order correlation coefficient (ROCC) for prediction monotonicity
    - Nonlinear regression between DMOS and output values of models before calculating performance measures
- Comparison with other metrics :
  - PSNR, spatial mean SSIM, DWT-SSIM, and visual information fidelity (VIF)

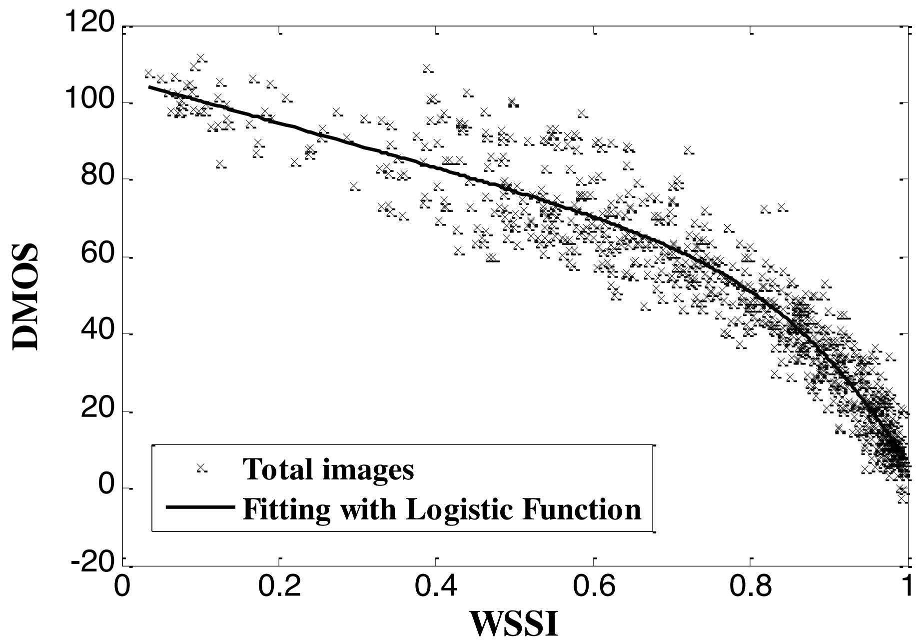
Simulation Results

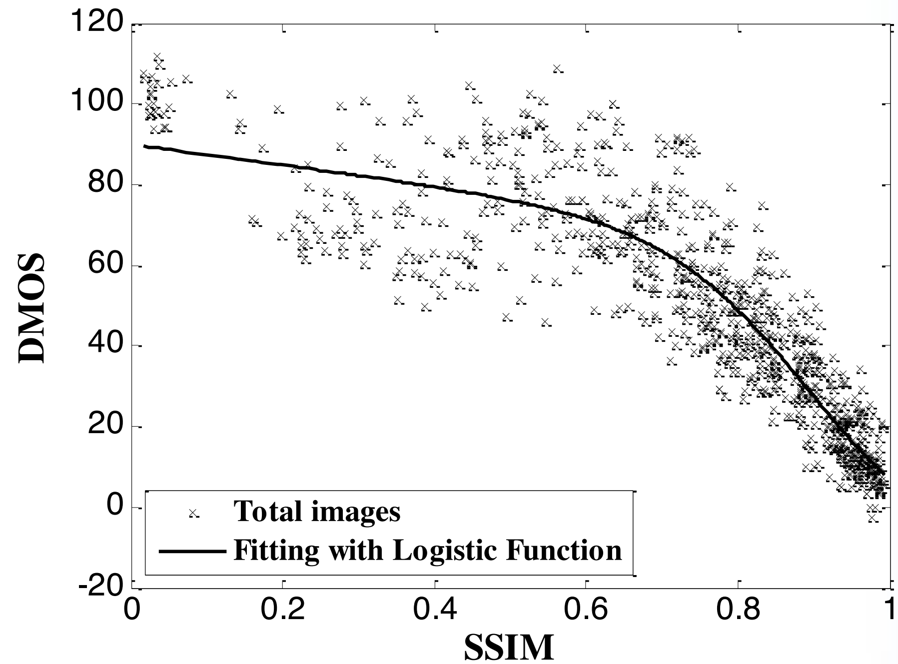
Model	CC	RMSE	ROCC
PSNR	0.8701	13.4685	0.8756
Mean SSIM (spatial)	0.9041	11.6736	0.9104
DWT-SSIM	0.9346	9.7201	0.9346
VIF	0.9593	7.7122	0.9635
Mean SSIM$_A$	0.9412	9.2270	0.9441
WSSI	**0.9548**	**8.1176**	**0.9586**

- WSSI uses: Haar wavelet, 4×4 Gaussian sliding window, and $\alpha = 0.94$
- SSIM$_A$ performs well as a separate quality metric
- ❑ The first-level approximation subband contains most of the image information
- Performance of WSSI is close to VIF but with much less complexity

Simulation Results: Scatter Plots

- Scatter plots of DMOS versus model prediction for all 779 distorted images
  - WSSI is more consistent with the subjective scores than the spatial mean SSIM



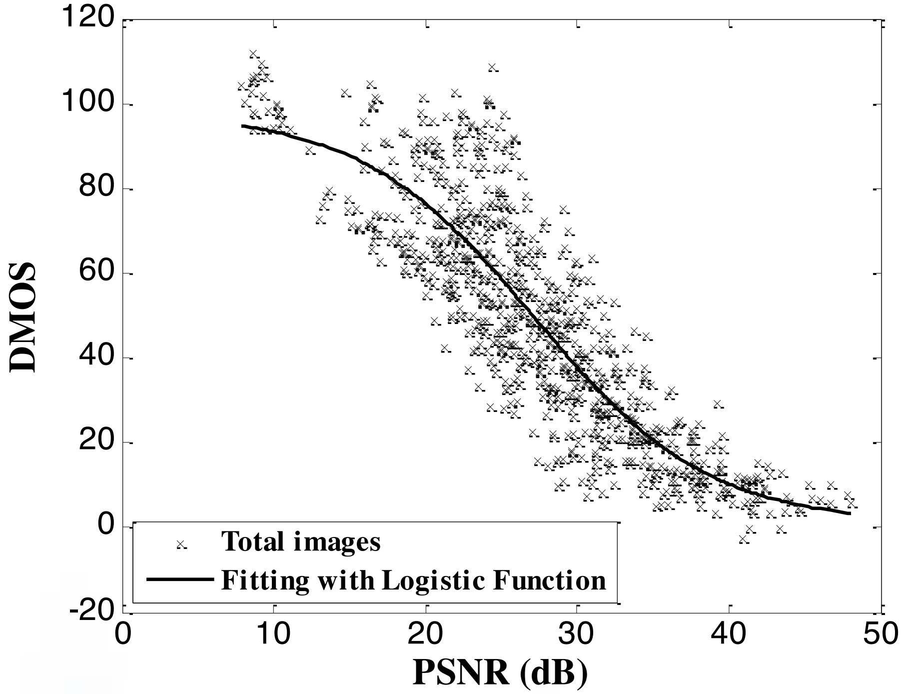


Simulation Results

➢ Wavelet basis has very little effect on performance of the algorithm:

- Contrast map is image-adaptive and changes with the wavelet
- For Daubechies 9/7 wavelet & previous parameters (α and window size) :

CC= 0.9489 , RMSE=8.6232 , ROCC=0.9529



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4. Conclusion

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Conclusion

- A DWT-based framework for computing image quality
  - excellent trade-off between accuracy and complexity

- The performance of wavelet structural similarity index (WSSI) is close to VIF index
  - The complexity of WSSI is less than spatial-domain SSIM index
  - The complexity of WSSI is much less than VIF index

- A novel contrast map for pooling of distortion map in the discrete wavelet domain

- First-level approximation subband has a significant role in improving quality assessment
  - Haar wavelet gives slightly better results compared to other wavelet bases

THANKS FOR YOUR ATTENTION