Corrupted-Reference Image Quality Assessment

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1. Background

What is the best way to assess the quality of restored images?

- How close is \( \hat{x} \) to \( x \)?

- Comparison between \( i \) and \( x \) is called full-reference image quality assessment (FR-QA)

- Problem: We do NOT have \( x \)

- Solution: We will show that FR-QA can be computed without \( x \) (in many cases)

2. Corrupted-Reference Image Quality Assessment (CR-QA)

Definition CR-QA is a system in that makes equivalent to

Properties of CR-QA

- \( Q_4r(x,y) = Q_4c(x,y) \)

- \( Q_4c(x,y) \) is computed without \( x \)

We can design CR-QA using Stein’s Lemma (Stein 1981)

MSE (Donoho 1995)

\[
\text{MSE}(x, \hat{x}(y)) = E[(x - \hat{x}(y))^2]
\]

SURE (Donoho 1995)

\[
\text{SURE}(x()|y) = E[(x(y))^2 + \| \hat{x}(y) \|^2 - 2x(y)\hat{x}(y) + 2\sigma_x'^2(y) - \sigma_y^2]
\]

FR-SSIM (Wang 2004)

\[
\text{SSIM}_F(x, \hat{x}(y)) = \left( \frac{2\mu_x\mu_{\hat{x}} + \sigma_x + \sigma_{\hat{x}}}{\mu_x^2 + \mu_{\hat{x}}^2 + \sigma_x\sigma_{\hat{x}}} \right) \left( \frac{2\sigma_x\sigma_{\hat{x}} + \sigma_y}{\sigma_x^2 + \sigma_{\hat{x}}^2 + \sigma_y} \right)
\]

CR-SSIM (Cheng 2012)

\[
\text{SSIM}_C(x, \hat{x}(y)) = \left( \frac{2\mu_x\mu_{\hat{x}} + \sigma_x + \sigma_{\hat{x}}}{\mu_x^2 + \mu_{\hat{x}}^2 + \sigma_x\sigma_{\hat{x}}} \right) \left( \frac{2\sigma_{\mu_xx}\sigma_{\mu_{\hat{x}}\hat{x}} + \sigma_{\hat{x}}}{\sigma_x^2 + \sigma_{\hat{x}}^2 + \sigma_y} \right)
\]

where

\[
\sum = \sum_x - \sum_{\hat{x}} - \sum_y + \sum_{\hat{x}}\sum_{\hat{y}}
\]

and \( J_x() \) is Jacobian matrix.

3. Experimental Verification

Conclusion: CR-QA predicts FR-QA accurately.

4. Application

MSE optimal

CR-SSIM optimal

CR-VIF optimal

Example: Optimal Parameter Selection in Image Restoration (wavelet soft thresholding)

5. Generalization

- Variation to SURE has been developed for
  - deblurring (Eldar 2009)
  - denoising of Poisson-corrupted images (Hirakawa 2009, Luisier 2009)
  - denoising of Rician noise (Raphan 2007)
  - denoising of Speckle noise (Lazaro 2002 and Gupta 2004)
  - and many others (Raphan 2011)

- They can be leveraged for CR-QA under various image restoration scenarios. (Cheng & Hirakawa, in preparation)

6. Conclusion

- Proposed an alternative to full/reduced/no-reference image quality assessment metrics
- CR-QA is a new category of QA best suited for image restoration
- CR-QA predicts FR-QA scores without access to ideal reference image
- Showed denoising examples