QUALITY ASSESSMENT OF COMPRESSION TECHNIQUES FOR SYNTHETIC APERTURE RADAR IMAGES

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INTRODUCTION

• Synthetic Aperture Radar (SAR)
  – active remote sensing system
  – applications in agriculture, oceanography, target recognition, etc.

• Compression of SAR images
  – limited storage capacity
  – limited downlink capacity on mobile platforms

• Difference between SAR and optical images
  – speckle noise
  – high frequency components

• Commonly used quality measures (for both optical and SAR)
  – mean squared error (MSE)
  – peak signal-to-noise ratio (PSNR)
MOTIVATION AND CONTRIBUTIONS

• Assumption for MSE and PSNR
  – distortion is independent noise

• Distortion caused by compression algorithms
  – linear distortion
  – nonlinear distortion
  – additive noise

• No quality measure quantifies these distortions independently

• Contributions
  – Decouple and quantify linear distortion and additive noise
  – Introduce an edge correlation measure to quantify edge distortion
  – Apply to assess the quality of JPEG and SPIHT coders
**BACKGROUND**

- **Image coder model**
  - linear filter
  - additive uncorrelated noise

- **Distortion transfer function**
  - Deviation of the filter response from an all-pass response: $1 - H(\omega_1, \omega_2)$

- **Contrast sensitivity function** $C(\omega_1, \omega_2)$
  - frequency response of a human visual system model
  - weight the distortion measures with the contrast sensitivity function
DISTORTION MEASURES

- Linear distortion
  - Linear distortion measure (LDM)
    \[ LDM = \frac{\sum_{\omega_1} \sum_{\omega_2} |C(\omega_1, \omega_2)| \left| 1 - H(\omega_1, \omega_2) \right|}{\sum_{\omega_1} \sum_{\omega_2} |C(\omega_1, \omega_2)|} \]

- Noise injection
  - Weighted signal-to-noise ratio (WSNR)
    \[ WSNR = 10 \log_{10} \left( \frac{\sum_{\omega_1} \sum_{\omega_2} |X(\omega_1, \omega_2)C(\omega_1, \omega_2)|^2}{\sum_{\omega_1} \sum_{\omega_2} |D(\omega_1, \omega_2)C(\omega_1, \omega_2)|^2} \right) \]

- Nonlinear distortion
  - edge correlation measure
    - nonlinear distortion is hidden in the uncorrelated noise
    - appears as blocking effect and mosquito noise
    - predominantly high frequency effects
### EXAMPLE

<table>
<thead>
<tr>
<th></th>
<th>original image</th>
<th>white noise added</th>
<th>high-pass noise added</th>
<th>filtered (no noise)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PSNR</strong></td>
<td></td>
<td></td>
<td></td>
<td>23.1 dB</td>
</tr>
<tr>
<td>correlation with error</td>
<td></td>
<td>0.0089</td>
<td>0.0082</td>
<td>0.5919</td>
</tr>
<tr>
<td><strong>WSNR</strong></td>
<td></td>
<td></td>
<td></td>
<td>21.5 dB</td>
</tr>
<tr>
<td>correlation with error</td>
<td></td>
<td>1x10^{-6}</td>
<td>5x10^{-8}</td>
<td>9x10^{-6}</td>
</tr>
<tr>
<td>linear distortion measure</td>
<td></td>
<td>0.009</td>
<td>0.008</td>
<td>0.819</td>
</tr>
<tr>
<td>edge correlation</td>
<td></td>
<td>0.74</td>
<td>0.73</td>
<td>0.42</td>
</tr>
</tbody>
</table>

- Same PSNR for all three distorted images
- Proposed scheme gives different WSNR and quantifies the noise
- LDM quantifies the linear distortion
- Edge correlation quantifies the preservation of edge information\(^6\)
ESTIMATION OF LINEAR MODEL

- Divide the input and the output images into non-overlapping blocks of 64x64 in the DFT domain
- Rearrange the pixels for every input-output block pair to form the vectors $\mathbf{x}$ and $\mathbf{y}$
- Estimate a constant frequency response for every block using

$$e^{H\mathbf{x}} = (\mathbf{y} - H\mathbf{x})^H \mathbf{x} = 0 \quad \Rightarrow \quad H = \frac{\mathbf{y}^H \mathbf{x}}{\mathbf{x}^H \mathbf{x}}$$
JPEG vs. SPIHT

- Both PSNR and WSNR shows that SPIHT outperforms JPEG.
- For high compression ratios the performance difference is not as high as PSNR suggests.
- PSNR does not give any other information.
**JPEG vs. SPIHT**

- Similar performance for compression ratios close to two
- JPEG distorts more than SPIHT for high compression ratios
- Combining the results: SPIHT outperforms JPEG
  - due to less noise injection at low compression ratios
  - due to less linear and edge distortion at high compression ratios
CONCLUSION

• Lossy image compression subjects an image to
  – linear distortion
  – non-linear distortion
  – noise injection

• To measure these distortions we model a compression scheme as a linear filter followed by uncorrelated noise injection.

• We measure the non-linear distortion using edge correlation.

• We assess the visual impact of all three distortions in SAR images compressed by JPEG and SPIHT image coders.

• Our result is that SPIHT outperforms JPEG in all three measures.