Image Blur Estimation Based on the Average Cone of Ratio in the Wavelet Domain

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Contents

• Introduction
• The proposed blur metric
• Experimental results
• Real-time implementation
• Conclusions
• Future research
• **Blur** is usually observed as a loss of image sharpness which corresponds to *smoothening of the edges*.

• **Why blur evaluation?**
  – assessment of image quality
  – image restoration

• **Standard observation model**

\[
g(x, y) = h(x, y) * f(x, y) + n(x, y)
\]

- \( g(x,y) \) - degraded image
- \( h(x,y) \) - blurring function (PSF)
- \( f(x,y) \) - ideal image
- \( n(x,y) \) - noise
**Lipschitz exponents**

... characterize the regularity of the signals

Using wavelet transform to estimate local Lipschitz exponent, $\alpha$

- [Jaffard, 1991]
- [Mallat and Zhong, 1992]
- [Malfait and Roose, 1997]
- [Hsung *et al.*, 1999]
- [Pizurica *et al.*, 2002]

Pointwise Lipschitz exponents
[courtesy of A. Pizurica]

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*Pointwise smoothness, two-microlocalization and wavelet coefficients, Jaffard, 1991*

*Characterization of signals from multiscale edges, Mallat and Zhong, 1992*

*Wavelet-based image denoising using a markov random field a priori model, Malfait and Roose, 1997*

*Denoising by singularity detection, Hsung et al., 1999*

*A joint inter- and intrascale statistical model for wavelet based Bayesian image denoising, Pizurica et al., 2002*
Average cone ratio, ACR  [Pizurica et al. 2002]

Average cone ratio (ACR)

describes the “collective” evolution of the wavelet coefficients inside a cone of influence centred at the spatial position \( l \).

\[
\beta_{n \to k,l} = \log_2 \left( \frac{1}{k - n} \sum_{j=n}^{k-1} \left| I_{j+1,l} \right| \right), \quad I_{j,l} = \sum_{m \in C(j,l)} |\omega_{j,m}| \]

• Properties of ACR
  – good estimate of the local Lipschitz exponent \( \alpha \)
  – significant robustness to noise

Average point ratio (APR)

describes the evolution of the individual wavelet coefficients at the spatial position \( l \).
Average **Point Ratio** vs. Average **Cone Ratio**

- ACR is able to better separate the noise from the useful edges

Conditional densities of APR and ACR, computed from scales $2^1 - 2^4$. The standard deviation of added noise is $\sigma = 25$. [courtesy of A. Pizurica]
ACR metric. Probability density function

- Degradation free
- Noisy ($\sigma^2=25$)
- Blurred ($r=3$)
- Blurred ($r=3$) & Noisy ($\sigma^2=25$)
Low sensitivity to noise

Noise-free image

Noisy image (σ²=10)

Circular blur

Gaussian blur

Motion blur

PDF vs. ACR 2-4

Low sensitivity to noise

Noisy image

Noise-free image

Circular blur

Gaussian blur

Motion blur

PDF vs. ACR 2-4

Low sensitivity to noise

Noisy image

Noise-free image

Circular blur

Gaussian blur

Motion blur

PDF vs. ACR 2-4

Low sensitivity to noise

Noisy image

Noise-free image

Circular blur

Gaussian blur

Motion blur

PDF vs. ACR 2-4
New blur metric: CogACR

Image blur estimation based on the average cone of ratio in the wavelet domain, Platisa et al., 2009

Scenario 1. Reference image available
Scenario 2. Ref. image NOT available
Blur model. Circular blur (pillbox)

\[ h(x, y) = \begin{cases} 
0, & \sqrt{x^2 + y^2} > r \\
\frac{1}{\pi r^2}, & \text{otherwise}
\end{cases} \]

\[ r = \left\{ r \in \mathbb{R}: r_m = 0.25m, \quad m = 1, 2, \ldots, 20 \right\} \]

Example test image
Example test images [130 real images]
Space of values for CogACR

The results on 130 test images
Consistent behaviour for the whole range of tested blur
Extracting valid edges for ACR analysis

Edge detection based on:

a) THRESHOLDING WAVELET COEFFICIENTS

b) THRESHOLDING INTERSCALE PRODUCTS

Noise-free

Noisy $\sigma^2=10$

Noisy $\sigma^2=25$
Selecting the threshold

$V$  $H$

$T_p = 0.01$  $T_p = 0.10$

$T_p = 0.05$  $T_p = 0.10$

$T_p = 0.10$  $T_p = 0.15$

$T_p = 0.20$  

$C_{ogACR24}$

$T_p$ - threshold percent coefficient

Level of blur

CogACR24

$T_p = 0.01$  $T_p = 0.05$  $T_p = 0.10$  $T_p = 0.15$  $T_p = 0.20$
Selecting the threshold

![Graph showing the selection of thresholds](image)

- $T_p = 0.01$
- $T_p = 0.05$
- $T_p = 0.10$
- $T_p = 0.15$
- $T_p = 0.20$

The graph illustrates the level of blur at different thresholds, with $T_p$ values ranging from 0.01 to 0.20.
Selecting the threshold

- $T_p = 0.01$
- $T_p = 0.05$
- $T_p = 0.10$
- $T_p = 0.15$
- $T_p = 0.20$

Level of blur vs. $T_{p}$

$C_{ogACR24}$
Texture of the content

![Graph showing the relationship between CogACR24 and Level of blur for Image class A (diamonds) and Image class B (crosses).]
Texture of the content
No-Reference metric

![Graph showing the relationship between level of blur and the CogACR24 metric.

Legend:
- ♦ Ref. image available
- X Ref. image NOT available

The graph illustrates the increase in CogACR24 with a higher level of blur.

A reference image is available for 0 to 10 levels of blur.

CogACR24 increases proportionally with the level of blur.

No-reference metrics are those that do not require a reference image for evaluation.
No-Reference metric

![Graph showing the relationship between Level of blur and CogACR24, with symbols indicating whether reference image is available or not](image)

- ◊ Ref. image available
- x Ref. image NOT available
No-Reference image classification

• based on ACR histogram similarity, using histogram intersection metric

• *preliminary results*
No-Reference image classification

• based on ACR histogram similarity, using histogram intersection metric

  step1. compute the intersected section of the input image with the template histograms

  step2. select the best matching template histogram

  step3. calculate CogACR of the input image

  step4. based on CogACR curve of the selected image (template histogram), estimate the level of blur in the input image
No-Reference image classification

Input image

CogACR24

selected template

input image

Level of blur

0 2 4 6 8 10

0.5
0.75
1
1.25
1.5
1.75
2
No-Reference image classification

Level of blur

CogACR24

selected template
input image

Input image
No-Reference image classification

![Graph showing level of blur vs CogACR24 for selected template and input image.](image)

- **CogACR24** selected template
- **Level of blur**
- **Input image**

- Red squares: selected template
- Blue crosses: input image
Noisy images. Kurtosis vs CogACR


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**Kurtosis**

**CogACR**

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noise free

noisy, var=10

noisy, var=25
CogACR compared to other blur metrics

CogACR compared to other blur metrics

[Image 2]

# CogACR. Pros & Cons

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Range of distinguishable levels of Gaussian blur</td>
<td>$R \sim (0..1.5)$</td>
<td>$R \sim (0..2)$</td>
<td>$R \sim (0..3.5)$</td>
</tr>
<tr>
<td>Sensitivity to noise</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Computational complexity</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Image content dependency</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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</tbody>
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Real-time implementation

Cell Broadband Engine Architecture (CBEA): microprocessors dedicated to distributed data processing

- Computationally most expensive part is wavelet transform (~38% proc. time)
- Real-time performance requires multiple SPE cores (3 out of 8)
CBEA performance measurements

(a) Frame rate on single SPE core

(b) Frame rate of CogACR on multiple SPE cores
Conclusions

New metric of blur, \textit{CogACR}

- Sensitive to a wide range of blur levels
- Nearly insensitive to noise
- Valid in reference- and no-reference scenario
- Real-time performance could be achieved
- \textit{Current investigation}
  - \textit{automated content based image classification}
  - \textit{automated selection of }$T_p$
Directions for further investigation

- Work with blocks
- Use only the strongest edge in the image
- Work with the region of interest as seen by humans

- Consider using orientation sensitive wavelet-like transforms (*shearlets, curvelets, ...*)

Does where you gaze on an image affect your perception of quality? Applying visual attention to image quality metric, Ninassi et al., 2007
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Thank you!