Blind DT-CWT Domain Additive Spread-Spectrum Watermark Detection

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July 6, 2009

Overview

- Motivation for DT-CWT watermarking
- Host signal model for detection
- Performance evaluation
    - Perceptual quality assessment
    - Detection performance / Robustness against compression attack
- Conclusion

Motivation for DT-CWT Watermarking

Advantages over DWT

- Better orientational selectivity ($\pm 15°, \pm 45°, \pm 75°$ instead of 3 DWT subands)
- Approximately shift invariant.

Previous work

Previous work uses Gaussian host signal model; natural image DCT- and DWT coefficients significantly differ from Gaussian [Hernández et al., 2000]

- [Wang et al., 2007]: 3D CWT for video watermarking
- [Coria et al., 2008]: coarse detail coefficient for video watermarking
- [Woo et al., 2006]: DT-CWT on top of log-polar mapping for geometric invariance.
- [Tang and Chen, 2009]: motion estimation in the DT-CWT domain for energy-adaptive watermarking
- non-blind and visible watermarking [Mabtoul et al., 2007, Zhuang and Jiang, 2006]

Host signal model for detection

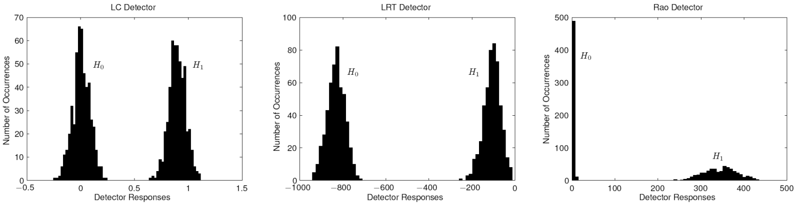
Propose to model the concatenated real and imaginary DT-CWT coefficients at scale ≥ 2 by a Generalized Gaussian Distribution (GGD).

	Orientation					
Scale	15°	45°	75°	-75°	-45°	-15°
1	6	6	6	6	6	6
2	0	0	0	1	0	0
3	1	0	0	1	0	0

Number of rejects on 6 test images for Kolmogorov-Smirnow test at 1% significance level

Comparing detectors: LC, LRT-GGD, Rao-GGD

- Linear correlation (LC): $\rho_{LC} = \frac{1}{N}\sum_{i=1}^{N} y_i w_i$
- Likelihood-ratio test conditioned on GGD [Hernández et al., 2000]:
  $$\rho_{LRT-GGD} = \sum_{i=1}^{N} \frac{1}{\alpha^{\beta}}\left(|y_i|^{\beta} - |y_i - g w_i|^{\beta}\right)$$
- Rao test conditioned on GGD [Nikolaidis and Pitas, 2003]:
  $$\rho_{Rao-GGD} = \frac{\left[\sum_{i=1}^{N} w_i \,\mathrm{sgn}(y_i)|y_i|^{\beta-1}\right]^2}{\frac{1}{N}\sum_{i=1}^{N} w_i^2\left(\sum_{i=1}^{N}|y_i|^{2\beta-2}\right)}$$



Detection threshold determination

- Theoretical threshold for LRT-GGD not applicable
  - need to estimate detection statistic parameters (μ, σ) under H_0
  - DT-CWT is a redundant transform; watermark embedded in the null-space is lost [Loo, 2002]
  - can still experimentally compute detection statistic parameters (cumbersome)
- No problem with Rao-GGD detector
  - χ^2 distribution, no parameters to estimate

GGD parameter estimation

- E.g. using Maximum-Likelihood Estimation (MLE) to estimate β $0 = 1 + \frac{\psi(1/\hat{\beta})}{\hat{\beta}} - \frac{\sum_{i=1}^{N} |x_i|^{\hat{\beta}} \log |x_i|}{\sum_{i=1}^{N} |x_i|^{\hat{\beta}}} + \frac{\log\left(\frac{\hat{\beta}}{N} \sum_{i=1}^{N} |x_i|^{\hat{\beta}}\right)}{\hat{\beta}}$
- Or using fast approximation (not discussed here)
- Or using fixed parameter: $\beta = 0.8$ or $\beta = 1.0$
- Note: MLE does not guarantee optimal detection, especially for Rao-GGD detector

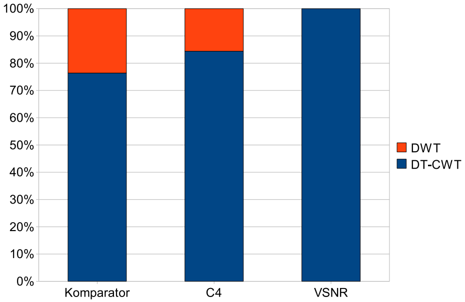
Perceptual quality assessment (1)

- Employ wPSNR/PQS [Miyahara, 1998], Komparator [Barba and Callet, 2003], C4 [Carnec et al., 2008] and VSNR [Chandler and Hemami, 2007] perceptual metrics
- Embedding with 36 dB PSNR in DWT and DT-CWT detail subband coefficients
- Simple perceptual shaping of watermark (proportional to coefficient magnitude)

Image	**wPSNR/PQS**		**Komparator**		**C4**		**VSNR**	
	DWT	DT-CWT	DWT	DT-CWT	DWT	DT-CWT	DWT	DT-CWT
Lena	45.88	**46.49**	992.28	**799.57**	0.939	**0.950**	23.48	**26.53**
Barbara	46.81	**47.26**	1045.24	**400.61**	0.954	**0.957**	24.63	**27.78**
Fabric	46.19	**46.90**	**198.86**	320.72	**0.966**	0.965	30.88	**34.67**
Bridge	45.96	**46.49**	556.719	**506.745**	0.941	**0.960**	26.21	**29.43**
Dromedary	45.95	**46.52**	1059.48	**387.69**	0.923	**0.946**	22.78	**25.56**
Models	45.75	**46.29**	672.59	**444.81**	0.957	**0.963**	28.60	**31.90**

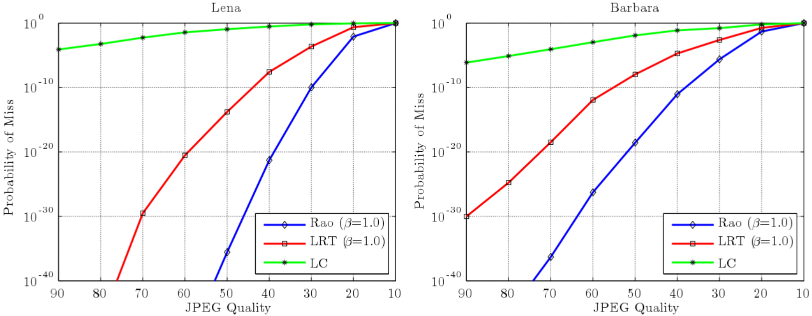
Perceptual quality assessment (2)

- Experiments with 500 grayscale images, same setup as before
- Number of images per embedding domain (DT-CWT vs. DWT) that were judged higher quality
  - Komparator: 382 DT-CWT / 118 DWT
  - C4: 422 DT-CWT / 78 DWT
  - VSNR: 500 DT-CWT / 0 DWT



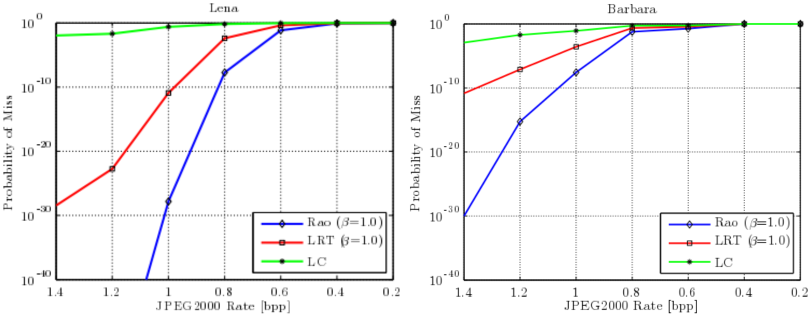
Detection performance under attack: JPEG

- Experimental evaluation with $N = 1000$ different watermarks embedded with DWR 16 dB
- Estimate detection statistic under H_0 (other watermark) and H_1 (correct watermark)
- Plot Probability of Miss P_m for False-Alarm Rate $P_f = 10^{-10}$ after JPEG compression



Detection performance under attack: JPEG2000

- Experimental evaluation with $N = 1000$ different watermarks embedded with DWR 16 dB
- Estimate detection statistic under H_0 (other watermark) and H_1 (correct watermark)
- Plot Probability of Miss P_m for False-Alarm Rate $P_f = 10^{-10}$ after JPEG2000 compression



Conclusion

- Concatenated real and imaginary DT-CWT detail subband components can be modeled by GGD
- Performance of linear correlation can be improved (non-Gaussian distribution) by Rao-GGD and LRT-GGD detector
- MLE of GGD shape parameter does not necessarily lead to best detection performance
- Objective perceptual assessment indicate higher quality of DT-CWT embedded watermark
- Source code available at `http://www.wavelab.at/sources`

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