Watermark Detection on Quantized Transform Coefficients Using Product Bernoulli Distributions

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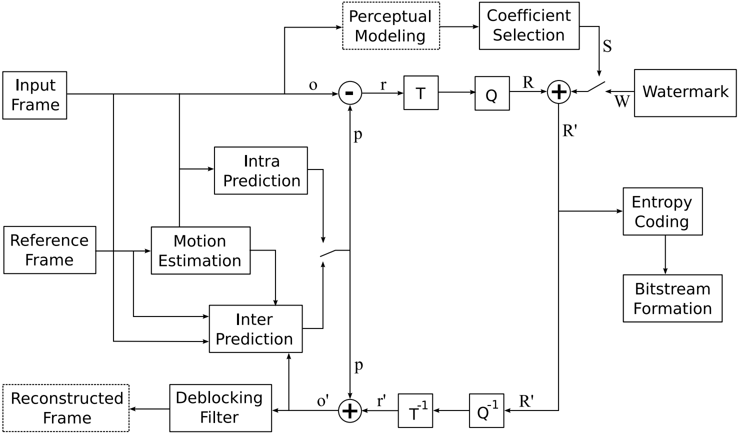
September 2010

Motivation

- Trying to detect spread-spectrum watermark in video coded with H.264
- Quantized DCT transform coefficients are non-Gaussian, yet it is difficult to improve upon linear correlation (LC) detector
- Previous attempts suggest that an optimal detector should be used, yet results are obtained with LC only [Noorkami and Mersereau, 2008]
- Difficulty in modeling the quantized transform coefficients, parameter estimation?

Motivation



[Noorkami and Mersereau, 2008]

Outline

- Quantized transform coefficient models
- LRT watermark detector based on Product Bernoulli bit plane model
- Experimental detection and runtime results
- Conclusion

Quantized Transform Coefficient Models

- DWT and DCT coefficients can be well modeled by a Generalized Gaussian distribution with scale parameter a and shape parameter c [Birney and Fischer, 1995]

$$\mathrm{p}(x; a, c) = \frac{c}{2a\Gamma(1/c)} \exp\left(-\left|\frac{x}{a}\right|^c\right)$$

- [Pi et al., 2006] propose a bit-plane model for quantized, absolute transform coefficients for texture retrievel applications

$$|x| = \sum_{i=1}^{B} 2^i X_i \quad \text{and} \quad \mathrm{p}(|x|) = p(X_1 = x_1, \ldots, X_B = x_B)$$

  where B is the number of bit planes and $X_i \in \{0, 1\}$ a random variable representing the binary value in plane i

- Use joint probability (Product Bernoulli) distribution model with parameters $p_i = \mathbb{P}(X_i = 1)$

$$p(X_1 = x_1, \ldots, X_B = x_B) = \prod_{i=1}^{B} p_i^{x_i}(1 - p_i)^{1-x_i}$$

Parameter Estimation

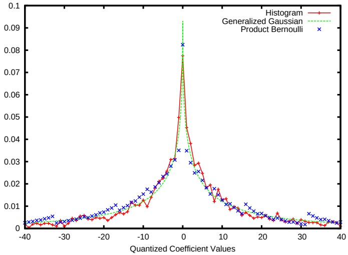
- For the Product Bernoulli model the maximum likelihood (ML) estimate for p_i [Choy and Tong, 2008] is

$$\hat{p}_i = \frac{1}{N}\sum_{k=1}^{N} x_i[k]$$

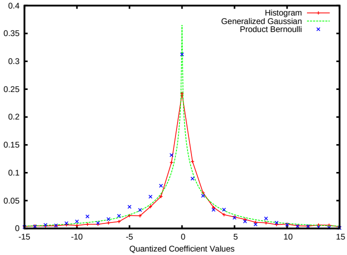
(simply counting the number of 1 occurencies per bit plane)

- For the GGD there are several approximate methods to obtain model parameters or a computationally intensive, iterative Newton-Raphson ML estimation procedure [Do and Vetterli, 2002]

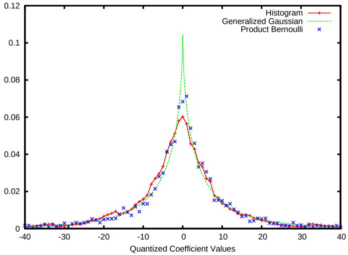
Quantized Transform Coefficient Histograms



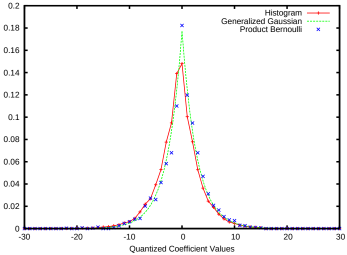
DWT, $\Delta = 1$



DWT, $\Delta = 5$



DCT, $\Delta = 5$



DCT, $\Delta = 25$

LRT watermark detector

- Assuming N quantized transform coefficients $\mathbf{x}$ with spread-spectrum watermark sequence $w[k] \in \{-1, 1\}$, $1 \leq k \leq N$, embedded in (selected) coefficients
- Adopt likelihood-ratio test (LRT) to decide between null hypothesis (not watermarked, $\mathcal{H}_0$) and alternative hypothesis (watermarked with $\mathbf{w}$, $\mathcal{H}_1$) on received signal $\mathbf{y}$

$$L(\mathbf{y}) := \log \frac{\mathrm{p}(\mathbf{y}|\mathcal{H}_1)}{\mathrm{p}(\mathbf{y}|\mathcal{H}_0)} > \log(\tau) =: T$$

LRT detector conditioned on host signal models

- Plugging in the GGD model [Hernández et al., 2000]

$$L_{\text{GGD}}(\mathbf{y}) = \frac{1}{a^c} \sum_{k=1}^{N} \left(|y[k]|^c - |y[k] - w[k]|^c \right)$$

- Plugging in the PBD model

$$L_{\text{PBD}}(\mathbf{y}) = \log \frac{\prod_{k=1}^{N} \prod_{i=1}^{B} p_i^{|y[k]-w[k]|_i} (1-p_i)^{1-|y[k]-w[k]|_i}}{\prod_{k=1}^{N} \prod_{i=1}^{B} p_i^{|y[k]|_i} (1-p_i)^{1-|y[k]|_i}}$$

- Rewrite by defining $\mathbf{z} := \mathbf{y} - \mathbf{w}$ and $p_i' := 1 - p_i$

$$\begin{aligned} L_{\text{PBD}}(\mathbf{y}) &= \sum_{i=1}^{B} \Bigg[\log p_i \sum_{k=1}^{N} |z[k]|_i + \log p_i' \sum_{k=1}^{N} (1 - |z[k]|_i) \\ &\quad - \log p_i \sum_{k=1}^{N} |y[k]|_i - \log p_i' \sum_{k=1}^{N} (1 - |y[k]|_i) \Bigg] \end{aligned}$$

Remarks and Performance Evaluation

- $L_{\text{PBD}}(\mathbf{y})$ is computed by summing up the number of 1 bits occurences per bit plane
- Parameter estimates are obtained for the PBD model in a similar way

- Detection statistics follow a Gaussian under $\mathcal{H}_0$ and $\mathcal{H}_1$
- Estimate parameters μ and σ under both hypothesis to set detection threshold T for false-alarm rate P_f and determine probability of miss P_m

$$P_f = \mathbb{P}(L(\mathbf{y}) > T|\mathcal{H}_0) = 1/2 \, \mathrm{erfc}\left(T - \mu_{\mathcal{H}_0} / \sqrt{2}\sigma_{\mathcal{H}_0} \right)$$

$$T = \sqrt{2}\sigma \, \mathrm{erfc}^{-1}(2P_f) + \mu_{\mathcal{H}_0}$$

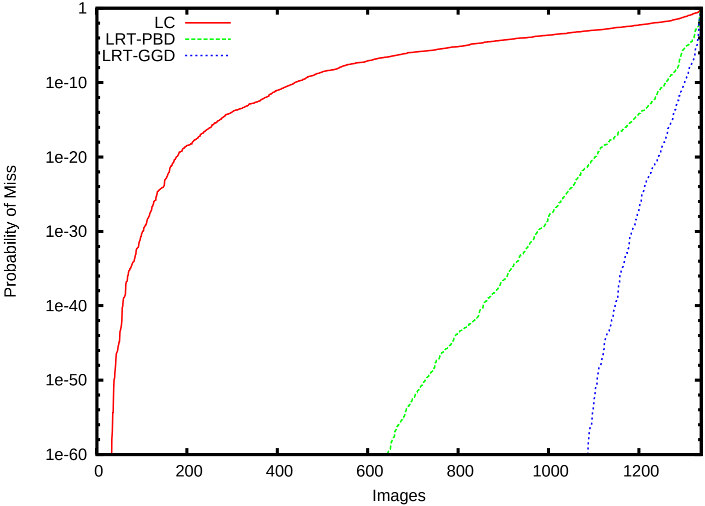
$$P_m = \mathbb{P}(L(\mathbf{y} < T|\mathcal{H}_1) = 1/2 \, \mathrm{erfc}\left(\mu_{\mathcal{H}_1} - T / \sqrt{2}\sigma_{\mathcal{H}_1} \right)$$

Experimental Results

Test detection performance (using LC, LRT-GGD, LRT-PBD detector) in terms of probability of miss on the UCID image database [Schaefer and Stich, 2004] (1338 images)

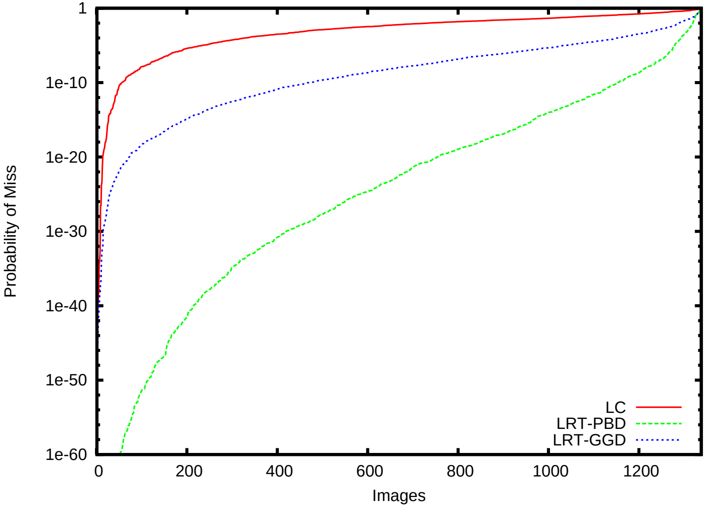
- with different quantization parameters
- with different embedding strategies
- after JPEG compression

Detection Performance, Embedding in all coefficients



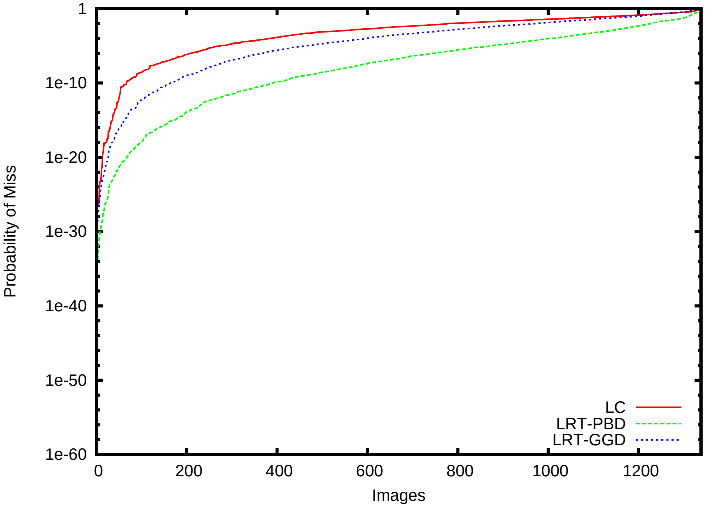
$\Delta = 10,\ P_f = 10^{-3},\ HL_3$ subband coefficients

Detection Performance, Embedding in non-zero coefficients



$\Delta = 10$, $P_f = 10^{-3}$, HL_3 subband coefficients

Detection Performance, Embedding in non-zero coefficients



$\Delta = 10$, $P_f = 10^{-3}$, HL_3 subband coefficients

JPEG compression ($Q = 70$)

Runtime results

Average runtime for detection statistic computation
(excluding model parameter estimation)

Detector	LC	LRT-PBD	LRT-GGD
Runtime (ms)	1.47	16.42	221.90

Signal length $N = 1000000$
Intel Core2 2.6 GHz CPU

LRT-PBD can be implemented with integer operations
LRT-GGD requires floating-point exponentiation

Conclusion

- Proposed watermark detector based on straightforward host signal model for quantized transform coefficients
- Applicable for watermark detection integrated with multimedia decoding
- Better results in case of rate-aware watermarking (embedding in non-zero coefficients only) and LUD detection scenario (embedding locations partially unknown, [Noorkami and Mersereau, 2008])
- Source code available at `http://www.wavelab.at/sources`

References

Birney, K. A. and Fischer, T. R. (1995).
On the modeling of DCT and subband image data for compression.
IEEE Transactions on Image Processing, 4(2):186–193.

Choy, S. K. and Tong, C. S. (2008).
Statistical properties of bit-plane probability model and its application in supervised texture classification.
IEEE Transactions on Image Processing, 17(8):1399–1405.

Do, M. and Vetterli, M. (2002).
Wavelet-based texture retrieval using Generalized Gaussian density and Kullback-Leibler distance.
IEEE Transactions on Image Processing, 11(2):146–158.

Hernández, J. R., Amado, M., and Pérez-González, F. (2000).
DCT-domain watermarking techniques for still images: Detector performance analysis and a new structure.
IEEE Transactions on Image Processing, 9(1):55–68.

Noorkami, M. and Mersereau, R. M. (2008).
Digital video watermarking in P-frames with controlled video bit-rate increase.
IEEE Transactions on Information Forensics and Security, 3(3):441–455.

Pi, M. H., Tong, C. S., Choy, S. K., and Zhang, H. (2006).
A fast and effective model for wavelet subband histograms and its application in texture image retrieval.
IEEE Transactions on Image Processing, 15(10):3078–3088.

Schaefer, G. and Stich, M. (2004).
UCID - an uncompressed colour image database.
In *Proceedings of SPIE, Storage and Retrieval Methods and Applications for Multimedia*, volume 5307, pages 472–480, San Jose, CA, USA. SPIE.