OUTLIER AGGREGATION TO PICK UP SCATTERED WATERMARK ENERGY

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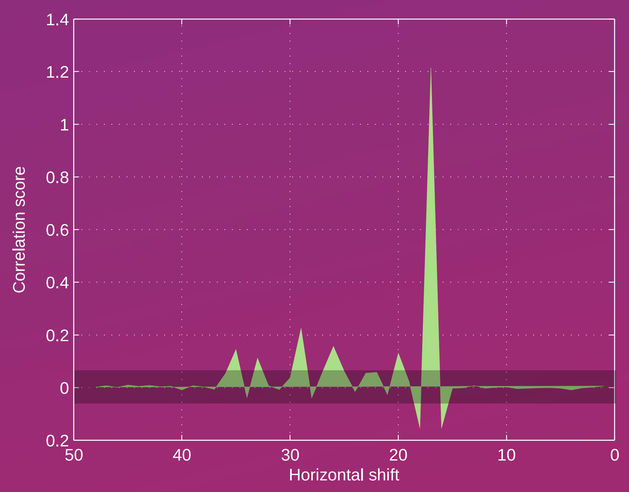
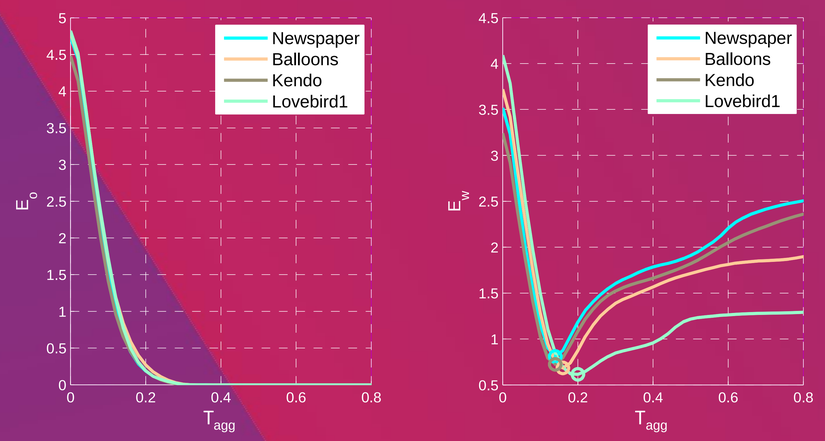
Disparity-coherent Watermarking for Stereo Video Content

- The embedding procedure guarantees that a physical point always carries the same watermark sample wherever it appears in the left and right views [1]

$$\mathbf{v}_{\mathrm{L}}^{(w)} = \mathbf{v}_{\mathrm{L}} + \alpha.\mathbf{w}_{\mathrm{L}}, \qquad \mathbf{w}_{\mathrm{L}} \sim N(0,1)$$
$$\mathbf{v}_{\mathrm{R}}^{(w)} = \mathbf{v}_{\mathrm{R}} + \alpha.\underbrace{\mathrm{warp}(\mathbf{w}_{\mathrm{L}}, \mathbf{d}_{\mathrm{L}}, \boldsymbol{\theta}_{\mathrm{L}}, \boldsymbol{\theta}_{\mathrm{R}})}_{\mathbf{w}_{\mathrm{R}}}$$

  - ☺ Improved robustness e.g. against view synthesis
  - ☺ Improved visual comfort thanks to lower interference with the HVS
  - ☹ Approximation in practice due to imperfect depth estimation [2]
- The detection procedure relies on horizontal cross-correlation and then aggregates correlation components exceeding a threshold prior to making a decision (*see figure below*) [3]
  - ☺ Accounts for the non-rigid horizontal displacements of the watermark due to view synthesis
  - ☺ No need for non-blind view parameters estimation
  - ☹ Aggregation threshold governs a complex trade-off noise sensitivity ↔ robustness





Deviation from the expected watermarking score (the lower, the better) averaged for different level of noise and for different reference videos

Setting the Aggregation Threshold

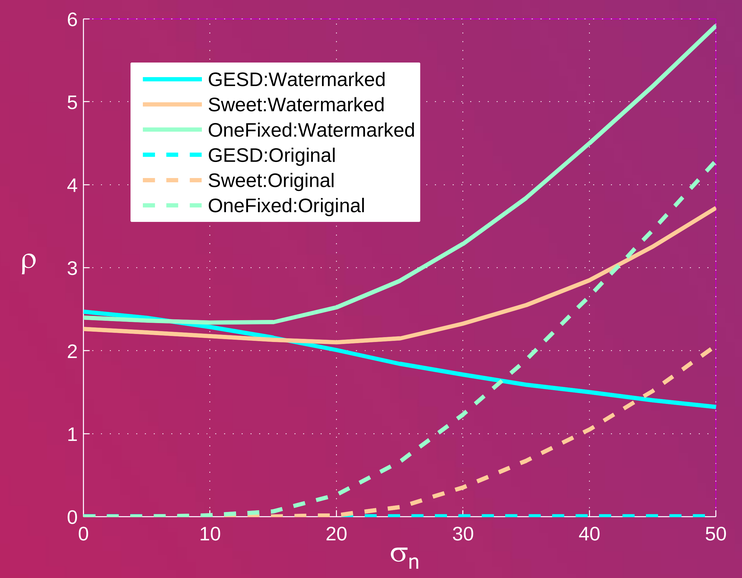
- Fixed threshold strategy [3]
  - ☹ Conservative setting in noiseless environment ⇒ watermark correlation components missed
  - ☹ Lack of adaptation beyond noise tolerance of the system ⇒ noisy components aggregation yielding false positives
  - ☹ Lack of content adaptability e.g. regarding scene depth complexity
- Content-optimized threshold strategy
  - ☺ Accounts for the fact that optimal average detection performances are achieved with different aggregation thresholds (*see figure above*)
  - ☹ Same lack of adaptation to varying noise conditions as the fixed threshold strategy
  - ☹ Unusable in practice
- Outlier detection strategy
  - ❖ Watermark signal introduces anomalous statistics compared to natural content [4]
    - ❑ Detect outliers in the correlation array and aggregate them to make the detection decision
    - ❑ Potential for automatic adaptation to the ambient level of noise
    - ❑ Number of outlier correlation components dependent on scene depth complexity and view parameters
  - ❖ Generalized Extreme Studentized Deviate (GESD) test [5]
    - ❑ Series of elementary tests to determine automatically the number or outliers and identify them

$$R_i = \max \frac{\left|\boldsymbol{\rho}[o] - \mu_{\boldsymbol{\rho}}^{(i)}\right|}{\sigma_{\boldsymbol{\rho}}^{(i)}} \lesseqgtr \lambda_i$$

    - ❑ A priori knowledge about the correlation array : $\mu_{\boldsymbol{\rho}}^{(i)} \approx 0$ and $\sigma_{\boldsymbol{\rho}}^{(i)} \approx \sigma_{\mathbf{c}}/\sqrt{S}$

Experimental Results

- Four reference stereo video sequences with disparity-coherent watermarks
- Detection using the three alternate aggregation strategies in the middle view
- Aggregated correlation score recorded for various noise levels (*see experimental results below*)
  - ❖ GESD detection grabs additional correlation energy in low noise regime
  - ❖ GESD detection is not impaired in high noise regime
  - ❖ Overall better detection statistics for original and watermarked content with GESD



Conclusion and Future Work

- Outlier detection offers means to flexibly adjust parameters in a watermark detection framework without making a priori assumptions on the worst case operating conditions
- Potential to exploit the temporal consistency of a scene to consolidate the identification of outliers in a correlation array
- Disparity-coherent watermarking continued e.g. multi-bit extension, psychovisual study to validate the conjectured benefit of disparity coherence
- Extension to other types of media e.g. audio watermarking and multi-path acoustic propagation

Key References

[1] **A. Coz, C. Cigla, and A. A. Alatan**, "*Watermarking of Free-view Video*", IEEE Transactions on Image Processing, 19(8):1785-1797, June 2010
[2] **H. Sheikh Faridul, G. Doërr. and S. Baudry**, "Disparity Estimation and Disparity-coherent Watermarking", in Media Watermarking, Security, and Forensics, vol. 9409 of Proceedings of SPIE, February 2015
[3] **C. Burini, S. Baudry, and G. Doërr**, "*Blind Detection for Disparity-Coherent Stereo Video Watermarking*", in Media Watermarking, Security, and Forensics, vol. 9028 of Proceedings of SPIE, February 2014
[4] **M. Urvoy and F. Autrusseau**, "*Application of Grubbs' Test for Outliers to the Detection of Watermarks*", in Proceedings of the ACM Workshop on Information Hiding and Multimedia Security, pp. 49-60, June 2014
[5] **B. Osner**, "*Percentage Points for a Generalized ESD Many-outlier Procedure*", Technometrics, 25(2):165-172, 1983

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