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]

\[
y^{(w)}(u) = y(u) + \alpha w_0 \quad w_0 \sim N(0,1)
\]

\[
y^{(w)}(u) = y(u) + \alpha \text{warp}(w_0, \theta_1, \theta_2)
\]

- 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

Setting the Aggregation Threshold

- Fixed threshold strategy [3]
  - Conservative setting in noisier 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
  - Unsuitable 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

\[
R_i = \max \left\{ \frac{|\mu_i^{(0)} - \mu_i^{(e)}|}{\sigma_i^{(e)}} \right\} \leq \epsilon
\]

- A priori knowledge about the correlation array: \( \mu_i^{(0)} = 0 \) and \( \sigma_i^{(e)} \ll \sigma_i^{(0)} \)

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