Watermarking of 2D Vector Graphics with Distortion Constraint

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Outline

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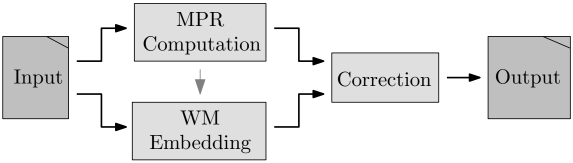
Problem Statement

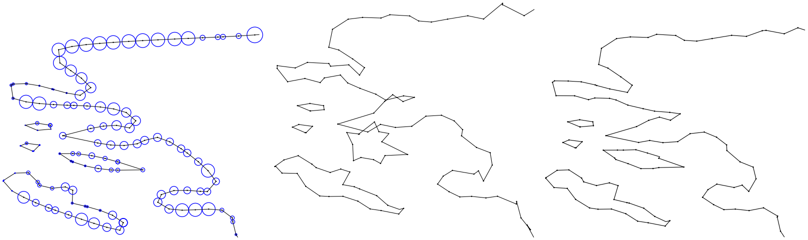
- Find geometric distortion constraint for watermarking of polygonal 2D vector data such that no line segments cross due to vertex perturbation.
- Application: watermarking of 2D GIS data, CAD models, etc.
- Similar in concept to just-noticeable difference (JND) constraint [Podilchuk and Zeng, 1998] for raster data.

Maximum Perturbation Regions

- The Maximum Perturbation Region (MPR) of a vertex v of a planar straight-line graph $G = (V, E)$ is the region $R(v)$ such that as long as the vertex is displaced within its $R(v)$ (and the incident line segments accordingly), the resulting set of edges remains crossing-free.
- We show how to efficiently compute MPRs based on the Voronoi diagram of G and test the impact on a well-known watermarking scheme [Doncel et al., 2007].

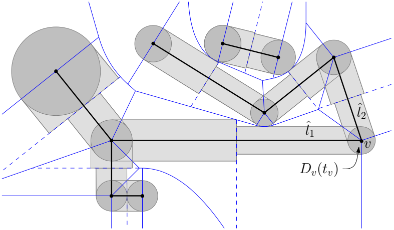


Example



(a) Data with MPRs (b) Watermarked data (c) Corrected data

Maximum Perturbation Region Computation

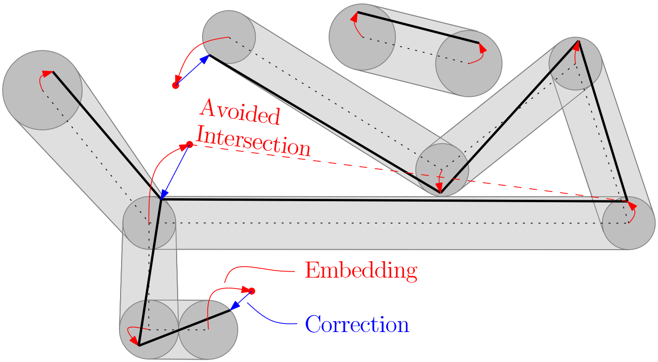


(d) Phase 1 (e) Phase 2

Phase 1: For each vertex v we determine the disc $D(t_v)$ centered at v with maximum radius t_v such that $D(t_v)$ and the area of the resulting 'hoses' is contained within the Voronoi cells of v and its incident half-line segments $\hat{l}_j$.

Phase 2: The radius of $R(v)$ is given by the minimum radius of the discs adjacent to v and t_v.

Perturbation Correction



In case a watermarked vertex v' lies outside its disc $R(v)$, v' is projected on the MPR boundary creating a new watermarked vertex v'' subject to the geometric distortion constraint:

$$v'' = v + \frac{r_v \cdot (v' - v)}{|v' - v|}$$

Computational Issues

- Voronoi diagrams can be computed in expected $O(n \log n)$ time [Held, 2001].
- Phase 1 and phase 2 of the MPR computation can be done in linear time.

MPR correction can be performed in two ways:

1. All vertices ouside their MPR are projected on their MPR boundary (in $O(n)$ time).
2. Only vertices with actually cause line segments to cross are corrected (denoted *conditional* MPR (cMPR), in $O(n^2)$ time due to line segment intersection problem).

Watermark Embedding

Use vector graphics watermarking approach based on Fourier descriptors [Solachidis and Pitas, 2004]. Polygonal chains are considered as a complex signal with the real and imaginary components being the x and y coordinates of the 2D vertices.

Multiplicative spread-spectrum embedding of a watermark **w**, $w_k \in \{-1, 1\}$, in a vector of selected complex DFT coefficient magnitudes $|\tilde{x}|$ of length n with strength α can be written

$$|\tilde{x}'_k| = |\tilde{x}_k|(1 + \alpha w_k) \quad \text{where} \quad 1 \leq k \leq n.$$

Watermark Detection

- Linear Correlation detection on received signal **z** against threshold T_ρ [Solachidis and Pitas, 2004]

$$\rho_{LC} = \frac{1}{n}\sum_{k=1}^{n} |\tilde{z}_k| w_k > T_\rho .$$

- Likelihood Ratio Test (LRT) conditioned on Rayleigh distribution host signal model [Doncel et al., 2007]

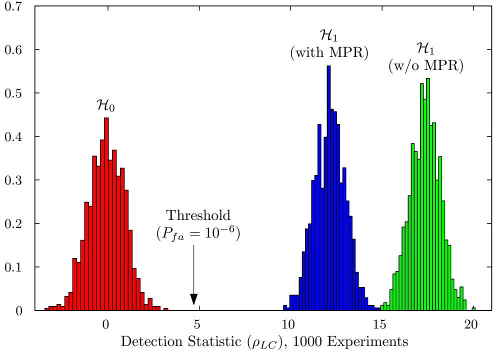
$$\rho_{LRT} = \sum_{k=1}^{n} |\tilde{z}_k|^2 \frac{(1+\alpha w_k)^2 - 1}{2\hat{\beta}_k^2 (1+\alpha w_k)^2} > T_\rho$$

where $\hat{\beta}$ is the ML estimate of the Rayleigh distribution parameter.

Detection Performance

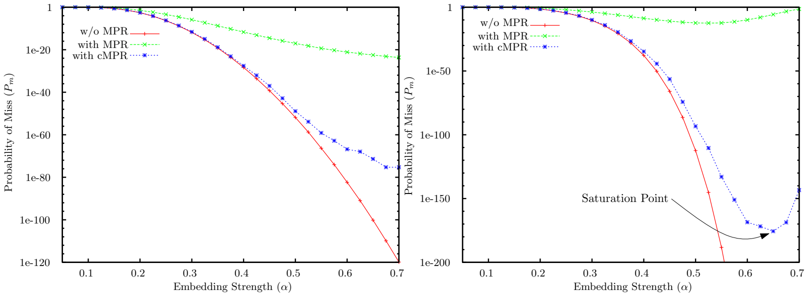
Detection statistics ρ_{LC} and ρ_{LRT} follow a Normal distribution under both hypothesis $\mathcal{H}_0$ and $\mathcal{H}_1$ [Barni and Bartolini, 2004]; parameters μ and σ can be estimated to determine a threshold $T_\rho = \sqrt{2}\hat{\sigma}_{\rho|\mathcal{H}_0}\,\mathrm{erfc}^{-1}(2P_f) + \hat{\mu}_{\rho|\mathcal{H}_0}$ and the experimental probability of miss

$$P_m = \frac{1}{2}\,\mathrm{erfc}\left(\frac{\hat{\mu}_{\rho|\mathcal{H}_1} - T_\rho}{\sqrt{2}\hat{\sigma}_{\rho|\mathcal{H}_1}}\right).$$



Experimental Results

- *Carp* data set consisting of 24134 vertices, 4890 vertices watermarked.
- Probability of false-alarm $P_f = 10^{-6}$. Simulation with 1000 test runs.



Conclusion and Outlook

- Introduced framework for watermarking of 2D vector data incorporating a geometric (MPR) distortion constraint.
- Applicable to robust watermarking schemes in coordinate and transform domain.
- Source code and supplementary material available at `http://www.wavelab.at/sources`.
- Extension to 3D vector data planned using conforming Delaunay triangulations.

References

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