Curve Reconstruction and Approximation in Binarised Scanned Historic Watermark Images

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1. INTRODUCTION

- **Curve reconstruction** - automatic derivation and filling of missing segments in curves.
- Can be very helpful to reconstruct curves from binarised images of watermarks in a watermark similarity matching system.
- **Wide variety of curves in watermarks**: singular, non-singular, open, closed, sharp bends, self-intersections

Figure 1: Binarised watermark image

2. RESEARCH QUESTION

How can line-reconstruction and hole-filling algorithms and models for binarised images aid watermark harmonisation to improve similarity matching and reduce user input?

3. METHODOLOGY

Dataset

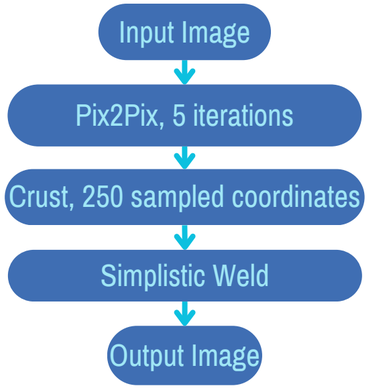
- automatically generated singular open and closed curves
- human-drawn sketches
- binarised watermark images

Gap Generation

- Keypoints preserved to enable maximal recovery
- Gaps generated in regions not within a certain radius of keypoints

Algorithms

- **Machine learning approach**: conditional generative adversarial networks (Pix2Pix)[1]
- **Analytical approach**: based on principles of connectivity and proximity (Crust)[2]
- **Hybrid approach**: Pix2Pix + Crust + simplistic weld algorithm (based on a distance, orientation, and angle threshold, Gestalt laws [3]).



Evaluation metrics

- Intersection over union (IoU) - how exactly the output and ground truth overlap
- Hausdorff distance (Hausdorff) - how far off the curves are
- Precision - how well-matched is the ground truth
- Recall - how much noise does the system introduce
- F1 score (F1) - balance between precision and recall

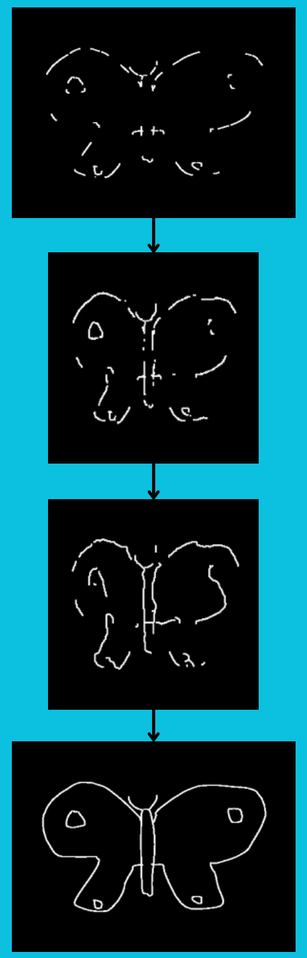


Figure 2: Hybrid approach curve reconstruction progression. Input (leftmost), ground truth (rightmost), predicted output after machine learning step (left, centre), and at the method end (right, centre).

4. RESULTS

- Hybrid approach compared to the pure baselines on the training and testing set (see Fig. 3)
- Predicted output compared to ground truth
- Evaluation of 150 training and 150 testing samples, 2:1 sketches to watermarks
- All approaches register low exact matches
- Curve mismatches are least severe for Pix2Pix alone
- Newly introduced noise is very low for all techniques
- Hybrid and machine-learning approaches fare a bit better on the training set than on the testing set.

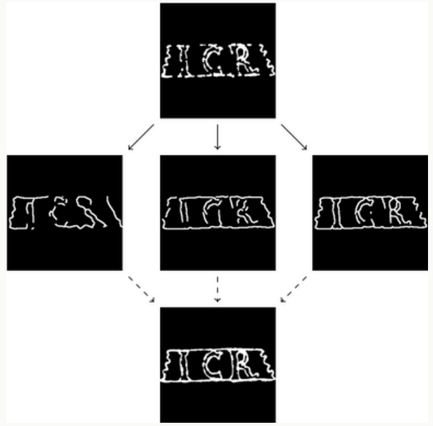


Figure 4: Visual comparison of the three approaches. Input (up), Crust method output (left), hybrid method output (centre), Pix2Pix method output (right), ground truth (down).

		IoU	Hausdorff	Precision	Recall	F1
Testing	Sketches	0.13	39.22	**0.66**	0.97	0.77
	Watermarks	0.12	**22.89**	0.54	1.00	0.68
	Total	0.13	34.00	0.62	0.98	0.74
Training	Sketches	0.14	33.15	**0.71**	0.98	0.81
	Watermarks	0.12	**20.86**	0.58	1.00	0.71
	Total	0.14	29.06	0.66	0.99	0.78

		IoU	Hausdorff	Precision	Recall	F1
Testing	Sketches	0.21	29.30	**0.75**	0.99	0.84
	Watermarks	0.19	**16.00**	**0.83**	1.00	0.89
	Total	0.20	25.04	0.78	0.99	0.85
Training	Sketches	0.21	31.88	**0.74**	0.98	0.83
	Watermarks	0.21	**13.90**	**0.91**	1.00	0.95
	Total	0.21	18.85	0.87	0.99	0.92

		IoU	Hausdorff	Precision	Recall	F1
Testing	Sketches	0.09	46.34	0.49	0.97	0.63
	Watermarks	0.07	38.64	0.22	0.98	0.35
	Total	0.09	43.89	0.40	0.97	0.54
Training	Sketches	0.09	51.37	0.46	0.97	0.61
	Watermarks	0.07	34.15	0.24	0.98	0.37
	Total	0.08	38.89	0.30	0.98	0.44

Figure 3: Evaluation results of the hybrid approach (up), machine learning approach (middle), analytical approach (down)

- Approximation of sketches of the hybrid and machine-learning approaches is comparable but the latter performs slightly better
- Approximation of watermarks is most successful in the pure machine learning method (see Fig. 3, 4)

5. CONCLUSION

- Machine learning approaches show promising but non-conclusive results.
- More research is needed for the analytical component.
- More accurate domain representation is needed

6. REFERENCES

[1] . Isola, J.-Y. Zhu, T. Zhou, and A. A. Efros, “Image-to-image translation with conditional adversarial networks,” CVPR, 2017.
[2] N. Amenta, M. Bern, and M. Kamvysselis, “A new voronoi-based surface reconstruction algorithm,” in Proceedings of the 25th Annual Conference on Computer Graphics and Interactive Techniques. ACM, 1998, pp. 415–421.
[3] Koffka, K. (1935). Principles of Gestalt psychology. Harcourt, Brace.