Combining Features and Intensity for Wide-Baseline Non-Rigid Surface Registration

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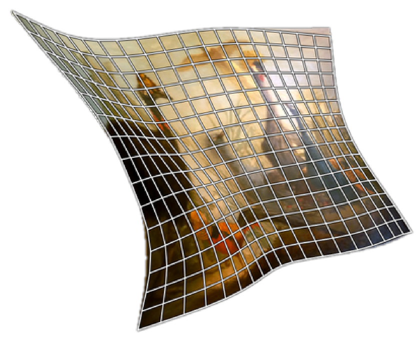
Problem

Input flat template $\mathcal{I}_0$

Input deformed surface $\mathcal{I}$

Input putative matches $\mathcal{F}$

Desired output



Process

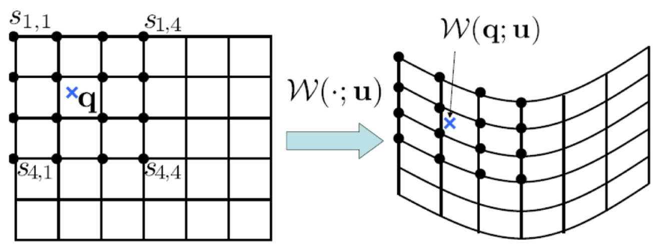
Closest work [3]

1. Match filtering
2. Warp fitting
3. Optional intensity-based refinement

Ours: joint optimization and filtering using putative matches and intensity

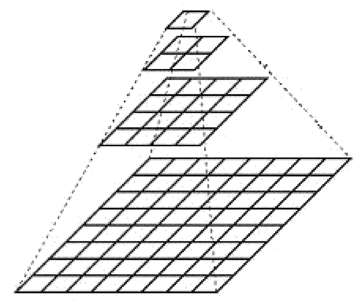
Deformation Model

Free-Form Deformation (FFD)
Displacement of control points: $\mathbf{u}$



Optimization scheme [2]

- Gauss-Newton optimization
- Sparse Jacobian
- Coarse-to-fine warping

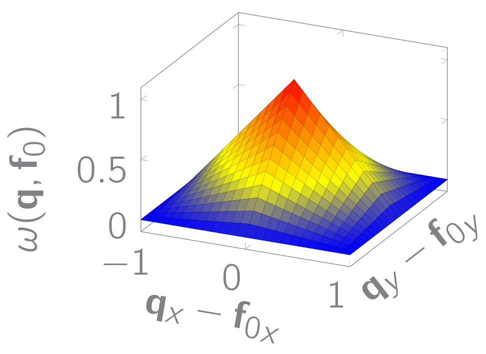


Minimize $\epsilon(\mathbf{u},\mathcal{F},\mathcal{I},\mathcal{I}_0) = \epsilon_{\text{features}}(\mathbf{u},\mathcal{F}) + \epsilon_{\text{regularization}}(\mathbf{u}) + \epsilon_{\text{shrinker}}(\mathbf{u}) + \epsilon_{\text{brightness}}(\mathbf{u},\mathcal{I},\mathcal{I}_0)$

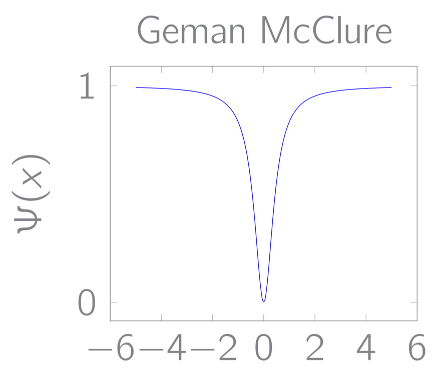
Feature-Based Cost

$$= \lambda_f \sum_{(\mathbf{f}_0,\mathbf{f})\in\mathcal{F}} \int_\Omega \omega(\mathbf{q},\mathbf{f}_0)\Psi_\sigma\left(\|\mathbf{u}-(\mathbf{f}-\mathbf{f}_0)\|_2\right) d\mathbf{q}$$

ω: bilinear weight function, 2×2 px support
influence decreases with resolution



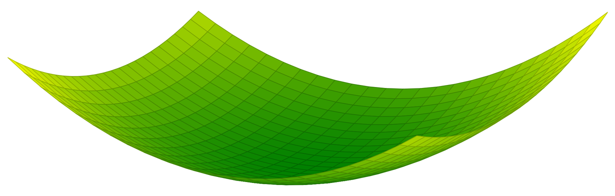
$\Psi_\sigma(x) = \frac{x^2}{\sigma+x^2}$: Geman McClure estimator
implicit filtering of outliers



Bending Energy

$$= \lambda_b \int_\Omega \left\| \frac{\partial \mathcal{W}^2}{\partial^2 \mathbf{q}}(\mathbf{q},\mathbf{u}) \right\| d\mathbf{q}$$

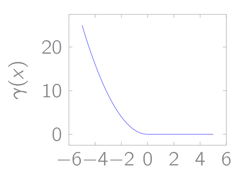
enforces **smooth deformations**



Shrinker

$$= \lambda_s \sum_{\mathbf{q}\in\Omega}\sum_{\mathbf{d}\in\mathcal{D}}\sum_{c\in\{x,y\}} \gamma\left\{\left(D^{(l)}_{\mathbf{d}}(\mathbf{q};\mathbf{u})\right)_c \left(D^{(r)}_{\mathbf{d}}(\mathbf{q};\mathbf{u})\right)_c\right\}$$

where $\gamma(x) = 0$ if $x \geq 0$ and x^2 otherwise



Penalizes sign changes of the partial derivatives: **prevents warp folding**

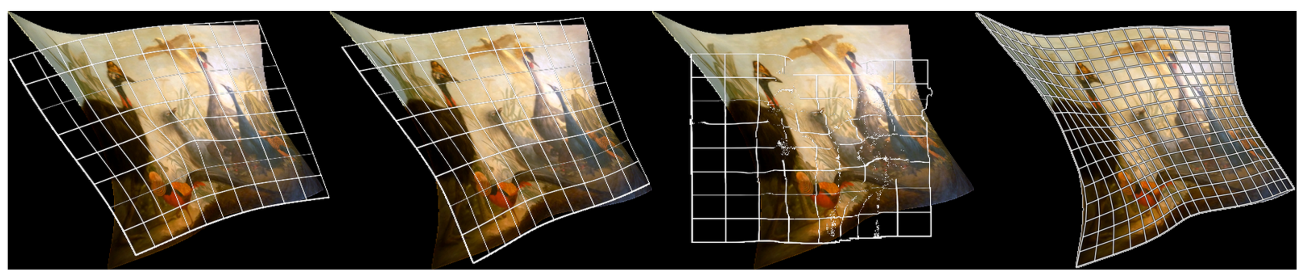
Brightness Constancy

$$= \lambda_d \sum_{\mathbf{q}\in\Omega} (1-\mathcal{P}_{\text{occ}})(\mathcal{I}_0(\mathbf{q}) - \mathcal{I}(\mathcal{W}(\mathbf{q};\mathbf{u})))^2$$

- Not enough for wide-baseline convergence
- Useful for **fine estimation**
- Greatly **improves accuracy**, especially in **low texture areas** and **near boundaries**

Qualitative Evaluation

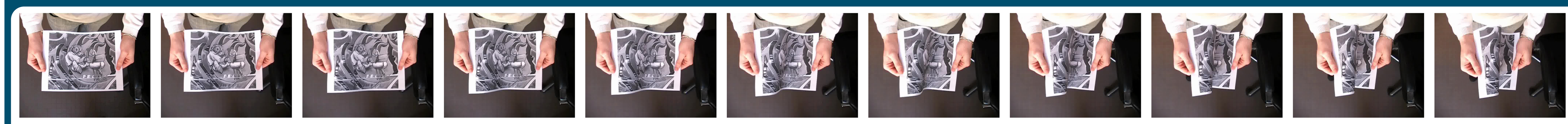
Comparison with state of the art

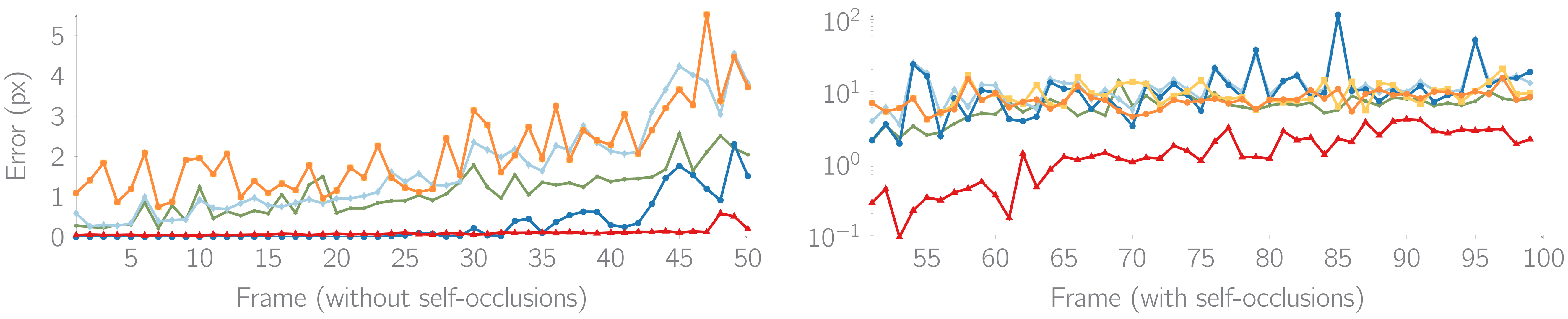


FBDSD [3] RANSAC [4] LDOF [1] Ours

Results on challenging images

Quantitative Evaluation





Registration error (px)	w/o SO	with SO
State of the art:		
RANSAC [4]	1.07	6.22
FBDSD [3]	1.59	14.06
FBDSD [3]+P [2]	0.29	12.74
Ours:		
Bending energy	2.02	9.14
. . . and shrinker	2.02	7.74
. . . and brightness	0.10	1.60

Conclusion and Future Work

→ We showed that our method is able to estimate **large deformations** even from **low-quality matches with outliers**.

→ The qualitative and quantitative evaluations showed an **increase in accuracy** compared to state of the art, especially in challenging cases where our method presents a **vastly increased convergence basin**.

→ The processing time (≈ 30s in Matlab) is on par with pixel-based methods since **the overhead of our feature term is insignificant**.

→ Future work involves developping a real-time implementation, incorporating new features (lines, curves, regions. . .), robustifying the pixel-based term to illumination changes and generalizing the approach to other problems such as optical flow.

[1] T. Brox and J. Malik. Large displacement optical flow: descriptor matching in variational motion estimation. *PAMI*, 2011.
[2] V. Gay-Bellile, A. Bartoli, and P. Sayd. Direct estimation of nonrigid registrations with image-based self-occlusion reasoning. *PAMI*, 2010.
[3] D. Pizarro and A. Bartoli. Feature-based deformable surface detection with self-occlusion reasoning. *IJCV*, 2012.
[4] Q. Tran, T. Chin, G. Carneiro, M. Brown, and D. Suter. In defence of RANSAC for outlier rejection in deformable registration. In *ECCV*, 2012.