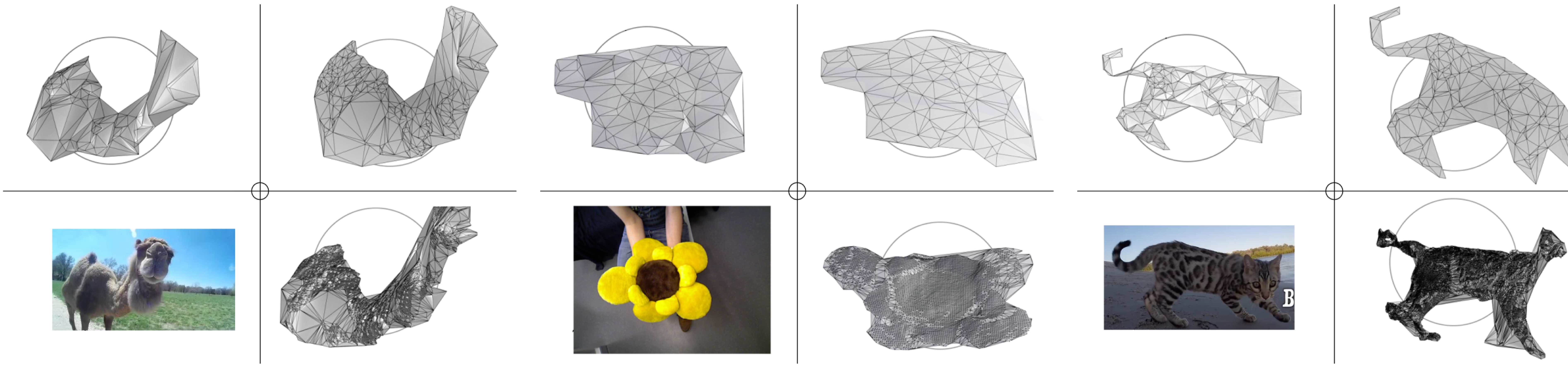
Incremental Non-Rigid Structure-from-Motion with Unknown Focal Length

Thomas Probst, Danda Pani Paudel, Ajad Chhatkuli, Luc Van Gool

Computer Vision Lab, ETH Zurich



Qualitative Results on YouTube videos. Comparison of our dense NRSfM method (bottom-right) to (Ji et al., 2017) (top-left) and (Dai et al., 2012) (top-right) on three different sequences.

How to reconstruct deforming objects from your favorite YouTube video?

- Input: dense 2D point tracks (optical flow).
- Output: dense 3D non-rigid reconstruction of the sequence
- NRSfM techniques for dense reconstruction of deforming surfaces from a YouTube video?

YouTube video		SotA NRSfM methods
Unknown object	$\Rightarrow$	no Shape-from-Template (SfT)
Unknown camera	$\Rightarrow$	no camera calibration
Dense reconstruction	$\Rightarrow$	high computational complexity

Isometric NRSfM

Reconstructing deforming objects from multiple images of a monocular camera is challenging.

- Infinite combinations of deformations and camera motions yield same projection

$\Rightarrow$ Severly underconstrained

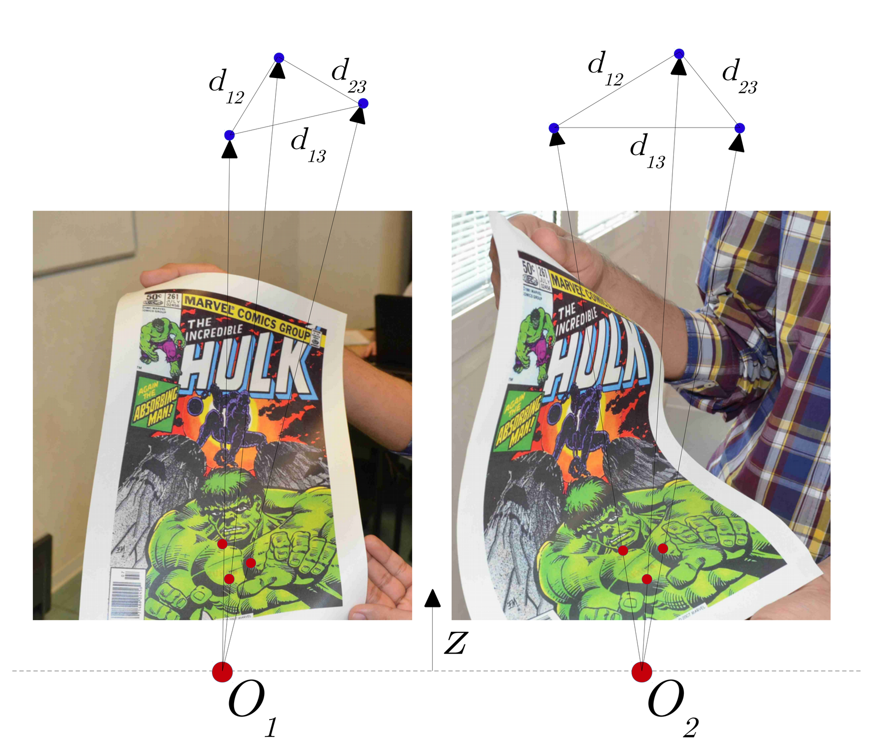
Isometric deformations.

- Geodesic distances are preserved
- Good approximation for many real deformations

Original Formulation

Given intrinsics K, template-less MDH can be written as a convex SOCP with inextensibility constraints (Chhatkuli et al., CVPR 2016):

$$\begin{aligned} \max_{\lambda_i^l, d_{ij}} \; & \sum_l \sum_i \lambda_i^l, \\ \text{s.t.} \; & \left\| \mathsf{K}^{-1}(\lambda_i^l \mathbf{u}_i^l - \lambda_j^l \mathbf{u}_j^l) \right\| \leq d_{ij}, \; j \in \mathcal{N}(i), \\ & \sum_i \sum_{j \in \mathcal{N}(i)} d_{ij} = 1. \end{aligned}$$



Reconstruction Upgrade

Given a reconstruction under $\hat{\mathsf{K}}$, we can approximate the reconstruction under K by upgrading the depth using

$$\lambda_i^l \approx \frac{\hat{\lambda}_i^l \left\| \hat{\mathsf{K}}^{-1} \mathbf{u}_i^l \right\|}{\left\| \mathsf{K}^{-1} \mathbf{u}_i^l \right\|}.$$

- Approximates local distances, error depends on point densities
- Relates reconstructions and distances as an analytic function of K
- No need for (expensive) re-reconstruction, given an initial reconstruction

Non-Rigid Camera Calibration

Incorrect intrinsics K affect angles between camera rays

- leads to distorted distances in reconstruction

$\Rightarrow$ K introduces errors in isometry $\Phi(\mathsf{K})$.

$\Rightarrow$ Isometry as certificate for correct intrinsics.

Based on this observation, we estimate the focal length in both template-based and template-less cases. The full intrinsics K can then be recovered through non-linear refinement.

Template-based

Isometric consistency w.r.t. template.

$$\Phi_T(\mathsf{K}) = \sum_i \sum_{j \in \mathcal{N}(i)} \left(d_{ij} - \hat{d}_{ij}(\mathsf{K}) \right)^2.$$

Degree 2 polynomials on IAC can be derived to generate hypotheses.

Template-less

Isometric consistency across views.

$$\Phi(\mathsf{K}) = \sum_k \sum_{l \neq k} \sum_i \sum_{j \in \mathcal{N}(i)} \left(\hat{d}_{ij}^k(\mathsf{K}) - \hat{d}_{ij}^l(\mathsf{K}) \right)^2.$$

Optimize by focal length a sweeping algorithm with iterative re-reconstruction.

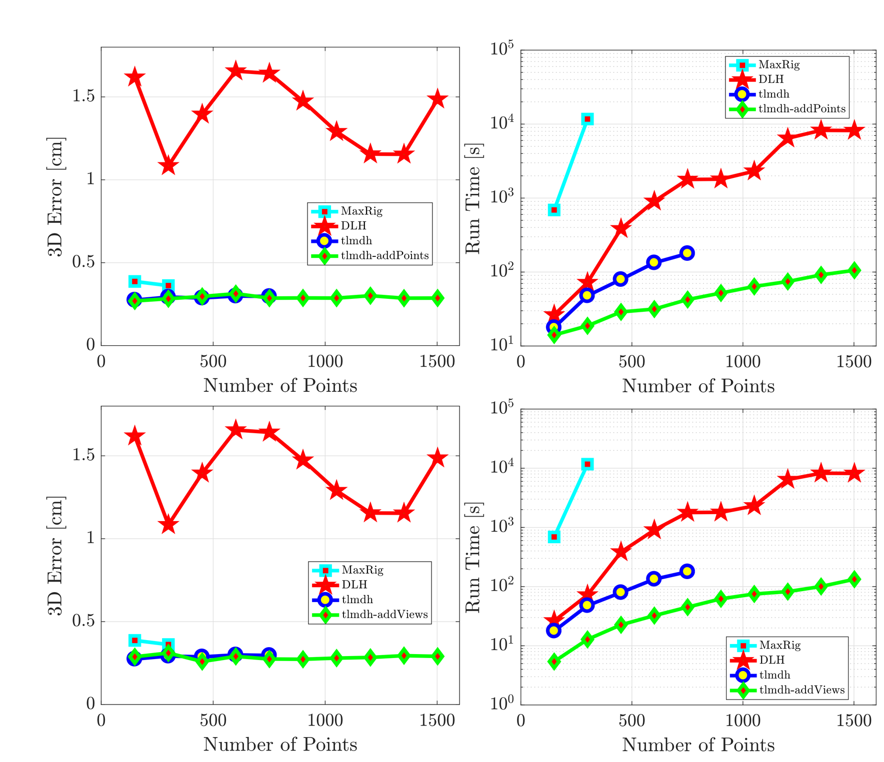
Incremental Dense NRSfM

Convex formulation to reconstruct additional points consistent with an initial reconstruction.

$$\begin{aligned} \max_{\zeta_i^l, e_{ij}, \alpha} \; & \alpha\Lambda + \sum_l \sum_{i \in \mathcal{Q}} \zeta_i^l, \\ \text{s.t.} \; & \left\| \hat{\mathsf{K}}^{-1}(\zeta_i^l \mathbf{u}_i^l - \alpha \lambda_j^l \mathbf{u}_j^l) \right\| \leq e_{ij}, \; j \in \mathcal{N}_p(i), \\ & \left\| \hat{\mathsf{K}}^{-1}(\zeta_i^l \mathbf{u}_i^l - \zeta_j^l \mathbf{u}_j^l) \right\| \leq e_{ij}, \quad j \in \mathcal{N}_q(i), \\ & \sum_i \sum_{j \in \mathcal{N}_q(i)} e_{ij} = 1 - \alpha, \end{aligned}$$

Adding views can be treated as an SfT problem.

$\Rightarrow$ Improved runtime and memory efficiency enables dense NRSfM.



Conclusion

We contribute theoretical insights and practical algorithms for the problem incremental dense NRSfM with unknown focal length. A convex formulation for incrementally adding points and views to an existing reconstruction lays the foundation for dense non-rigid reconstruction. Both contributions have immediate value for practical NRSfM applications.

NRSfM Toolbox

Check out our NRSfM MATLAB toolbox

- Implementations of our alogrithms
- Directly compare to state-of-the art NRSfM methods

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