Registration and 3D Reconstruction of Creased Surfaces by Shape-from-Template

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Introduction

Context

3D reconstruction of deformable objects from 2D images or videos

Three main approaches

Non-Rigid Structure-from-Motion (NRSfM)

Sequence of images

Shape-from-Template (SfT)

Template

Image

- One image
- No scale ambiguity

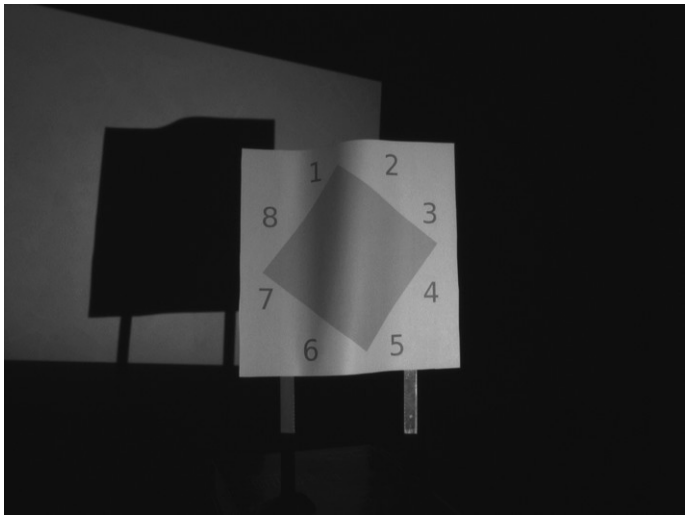
- Needs textured surfaces
- Assumes smooth deformations

Shape-from-Shading (SfS)

Light Reflectance Camera Response Image

State-of-the-Art

What is the problem with complex deformations and poorly-textured surfaces ?



Reduction of dimensionality or usual regularizers favour smooth deformations

Poorly-textured regions are interpolated by the textured regions

State-of-the-Art

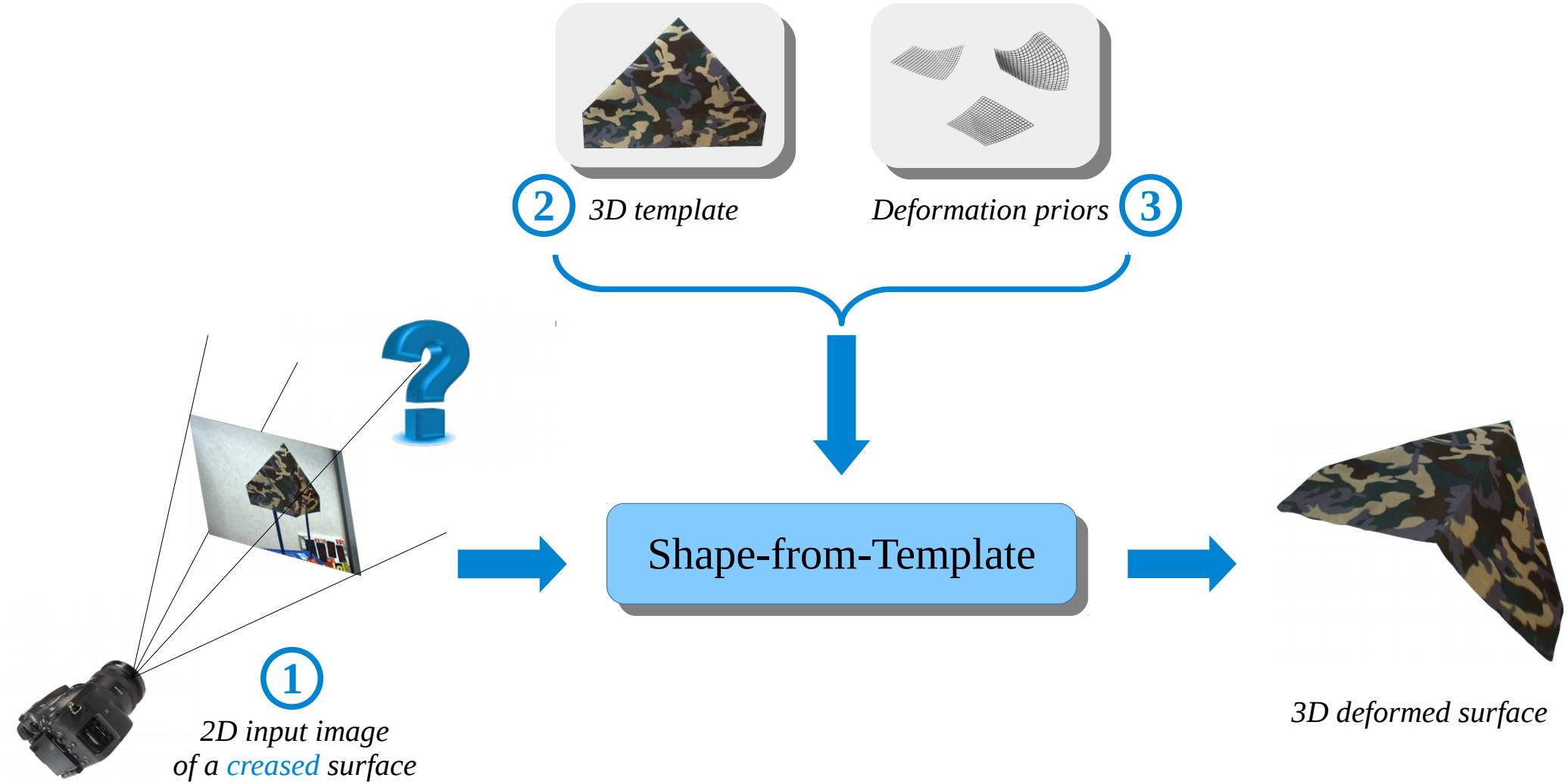
What is the problem with complex deformations and poorly-textured surfaces ?

Focus on complex deformations such as creases

Closest work [1] :
Reconstructed creases are a by-product

[1] : M. Salzmann and P. Fua. *Linear Local Models for Monocular Reconstruction of Deformable Surfaces*. IEEE Transactions on Pattern Analysis and Machine Intelligence, 33(5): 931–944, 2011.

Problem Definition



Assumptions

- Correspondences known
- Calibrated perspective camera
- No self-occlusions
- Isometric and **non-smooth** deformations
- 3D positions of creases **unknown**

Contributions

Optimising the template's shape using motion, boundaries and an adaptive smoothing term

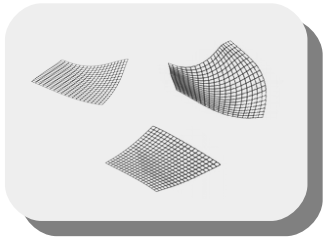
Without knowing a priori the location of creases

Reconstruct complex deformations such as creases

Solution Proposed

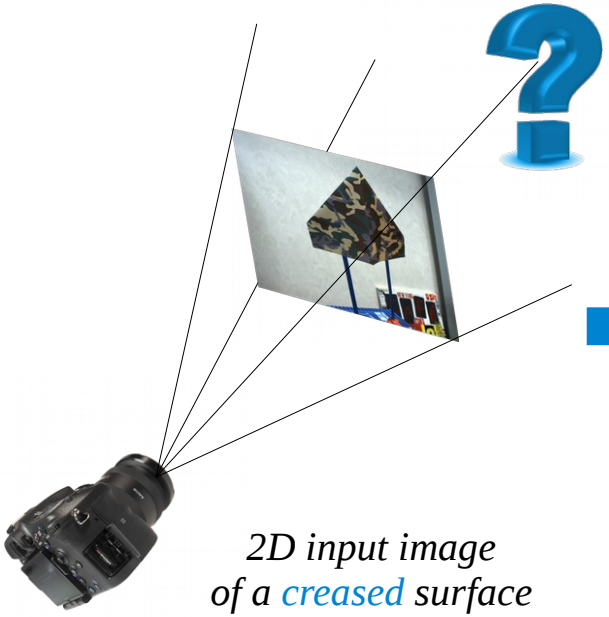
Shape and Deformation Model

3D template



Deformation priors

A Spatially-Varying Smoothing



2D input image of a creased surface

Shape-from-Template

Optimization Framework

3D deformed surface

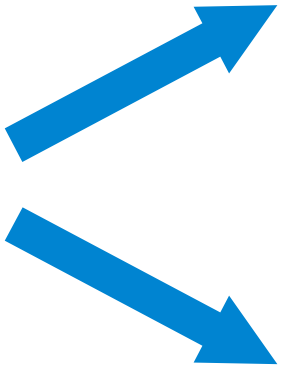
Solution Proposed

Shape and Deformation Model

Optimization Framework

A Spatially-Varying Smoothing

Dense regular triangular mesh



Position of each vertex in camera coordinates with an **unknown** 3D-vector

Allows complex deformation modelling

Solution Proposed

Shape and Deformation Model | **Optimization Framework** | A Spatially-Varying Smoothing

- **Unknowns** : position of each vertex in the camera coordinates frame
- **Initialization** using an existing SfT method [4]
- Non-convex **refinement**
  - Gradient-based optimization
  - Minimization of cost function

image constraints + deformation priors

- Motion of keypoints
- Reprojection of surface boundaries

- Isometry
- Smoothing

[4] A. Chhatkuli, D. Pizarro, and A. Bartoli. *Stable Template-Based Isometric 3D Reconstruction in All Imaging Conditions by Linear Least-Squares*. In International Conference on Computer Vision and Pattern Recognition, 2014

Solution Proposed

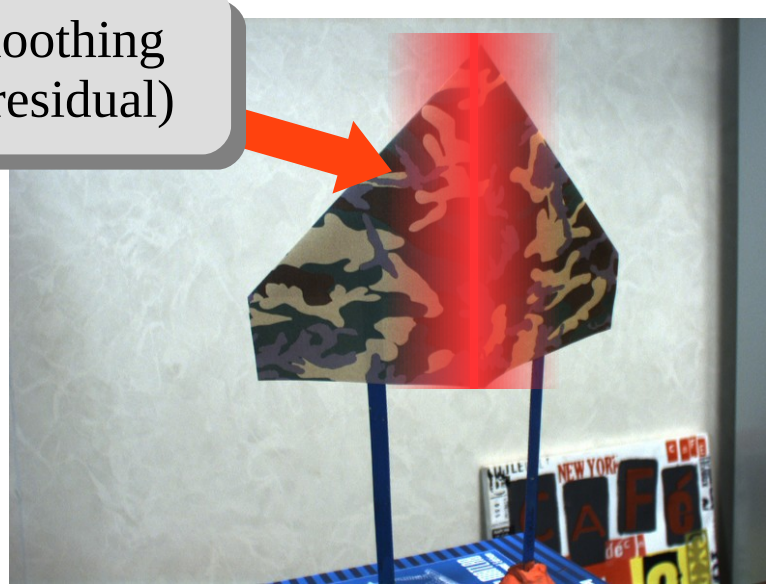
Shape and Deformation Model

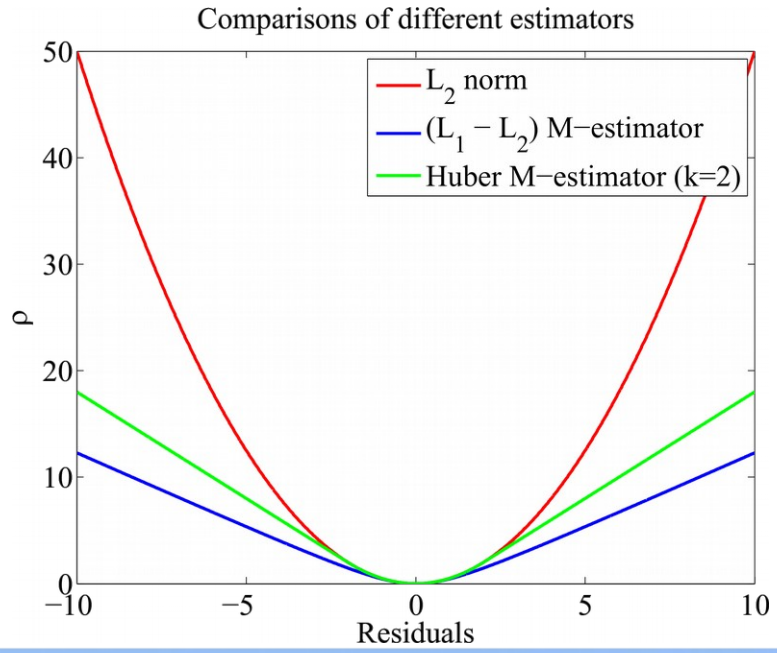
Optimization Framework

A Spatially-Varying Smoothing

- M-estimators : more robust
- Principle : fit to outliers
- Implementation

High smoothing error (=residual)





Solution Proposed

Shape and Deformation Model

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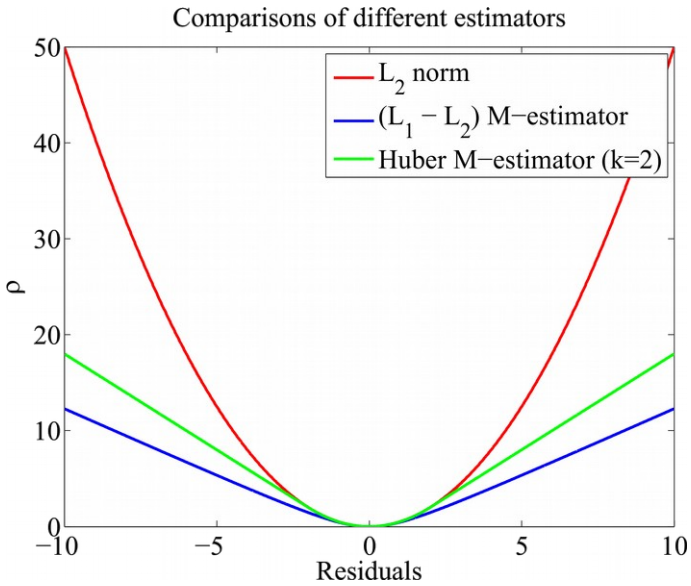


Experiments

Datasets

Sheet of paper

Paper plane

Cardboard box

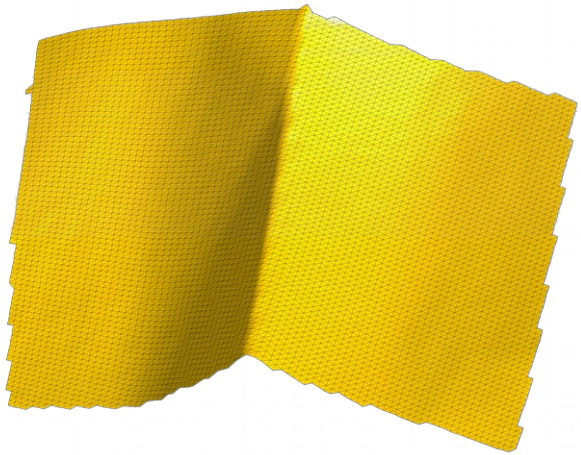
- ≈ 300 correspondences computed from [5]
- Possible mismatches
- 1000 boundary points

[5] : T. Collins, P. Mesejo, and A. Bartoli. *An analysis of errors in Graph-Based Keypoint Matching and Proposed Solutions*. In European Conference on Computer Vision, 2014.

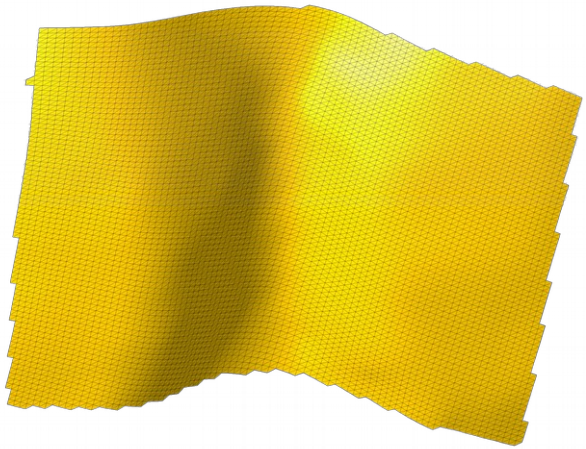
Experiments

Sheet of paper : 3D reconstructions

Input image



Ground truth

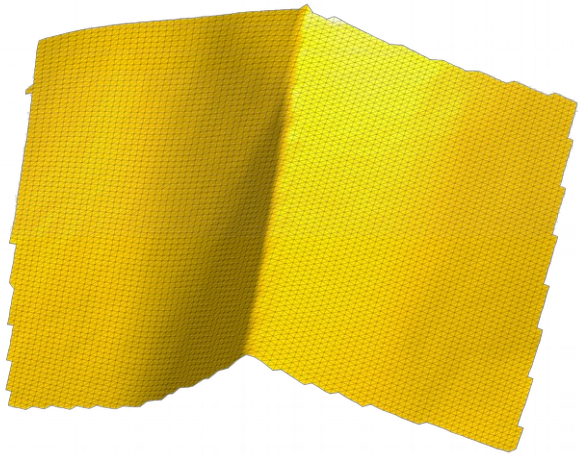


Best state-of-the-art : **ReD12**

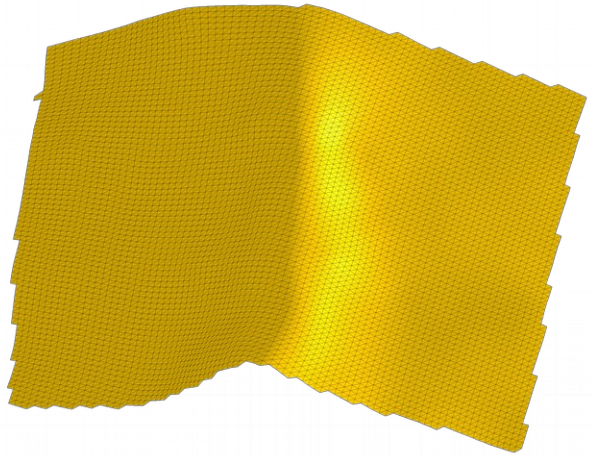
Experiments

Sheet of paper : 3D reconstructions

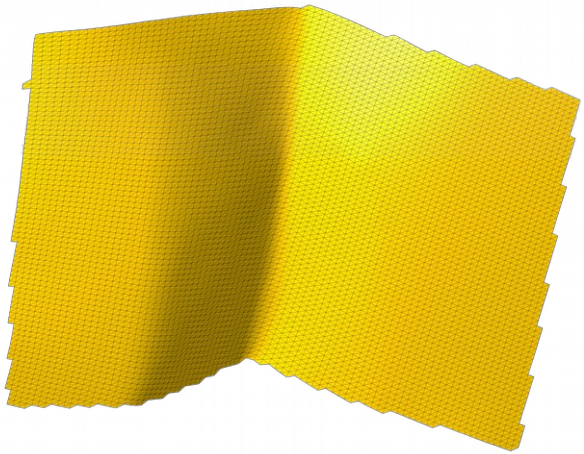
Input image



Ground truth



Ours_l2

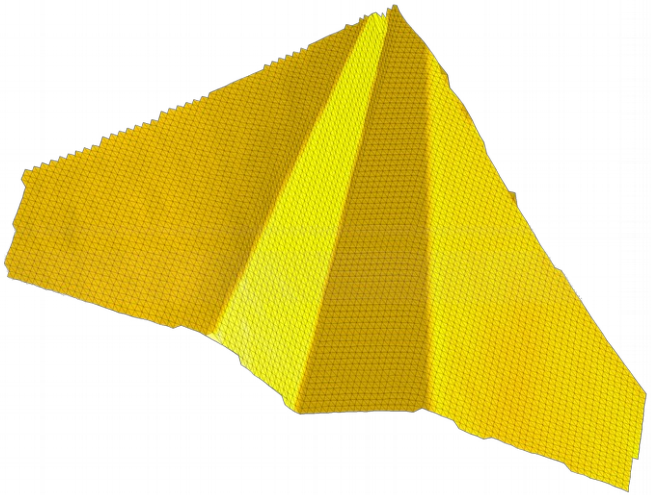


Ours

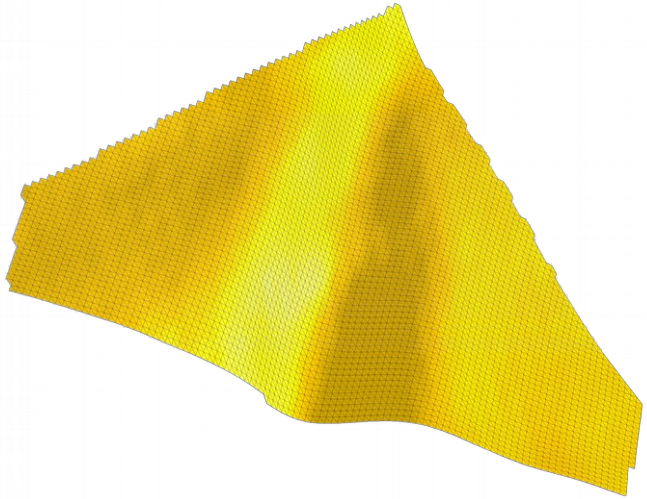
Experiments

Paper plane : 3D reconstructions

Input image



Ground truth

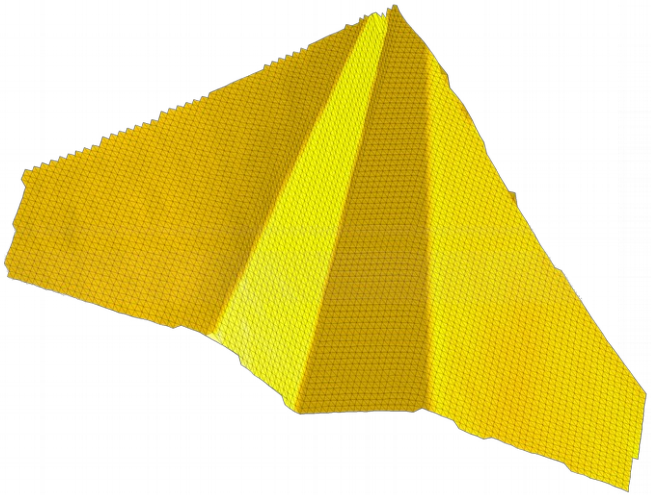


Best state-of-the-art : **ReD12**

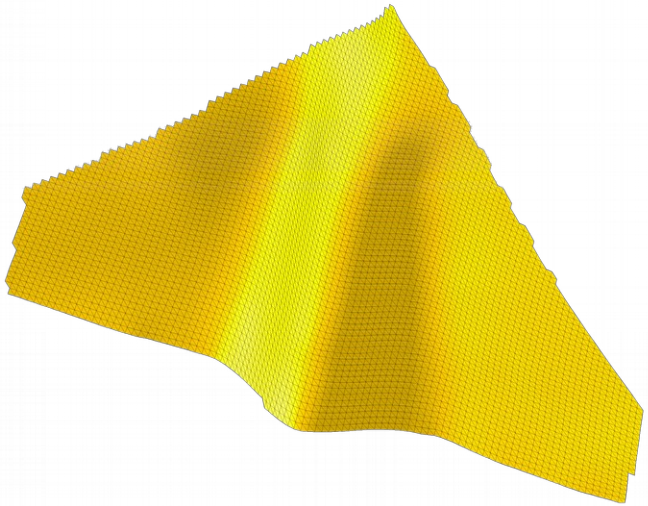
Experiments

Paper plane : 3D reconstructions

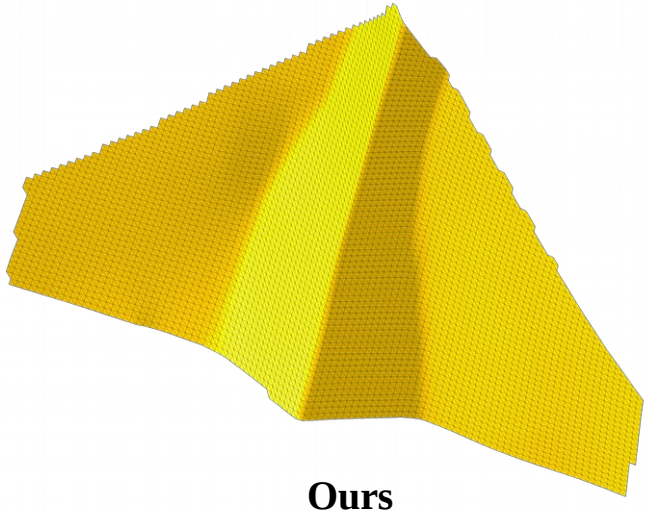
Input image



Ground truth



Ours_l2

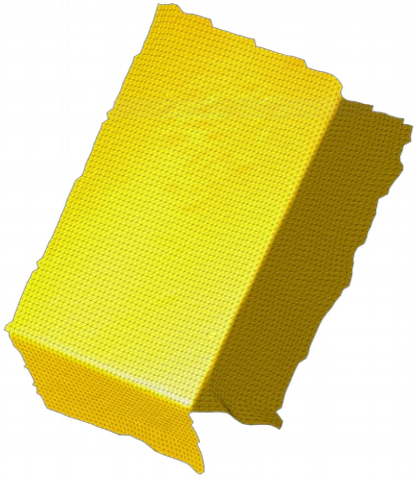


Ours

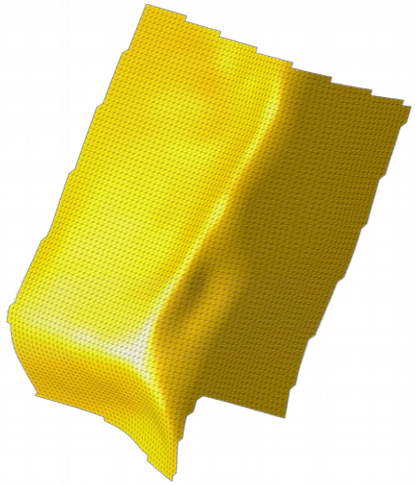
Experiments

Cardboard box : 3D reconstructions

Input image



Ground truth

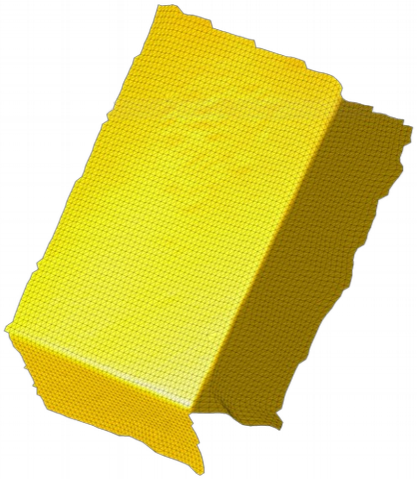


Best state-of-the-art : **ReJ14**

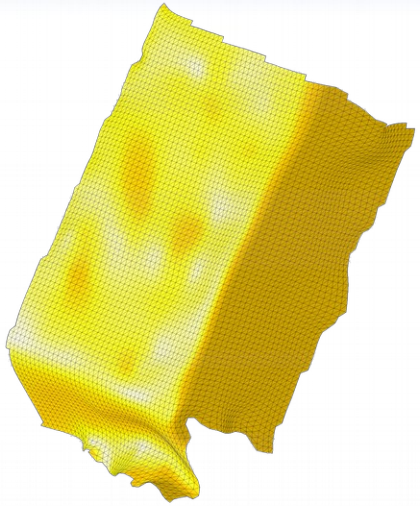
Experiments

Cardboard box : 3D reconstructions

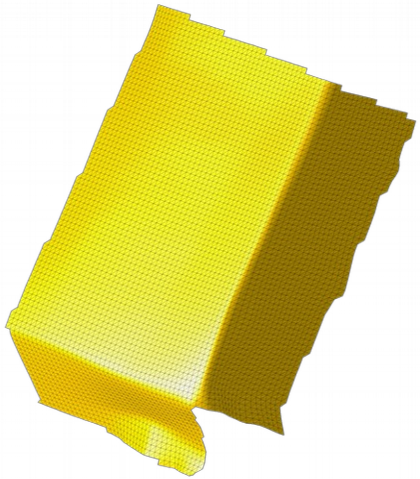
Input image



Ground truth



Ours_l2



Ours

Conclusion

- Solution to reconstruct complex deformations from a 2D image, a 2D template, motion and boundary constraints
- An adaptive smoothness term thanks to M-estimator
- No information of 2D/3D location of creases required
- Perspectives : handle false edges, poorly-textured surfaces with shading, self-occlusions,...

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