Using Shading and a 3D Template to Reconstruct Complex Surface Deformations

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Context and Motivations

Shape-from-Template:
3D reconstruction using the apparent motion of features between one single image and a 3D textured template

- One image
- No scale ambiguity (for isometry)

- Needs textured surfaces

Shape-from-Shading:
3D reconstruction using the relationship between pixel intensities, surface normals, light, camera response and surface reflectance

- One image
- Works with poorly-textured surfaces
- Dense constraint

- Ill-posed, up to scale
- Photometric calibration

Idea: Combining **motion** and **shading** to circumvent their drawbacks:
to handle **textured** and **textureless** regions and to reconstruct **complex** deformations

Previous Attempts

Shortcomings of [1,2,3]:

- non-joint use of motion and shading
- assume smooth surface and deformations
- require a complete a priori photometric calibration

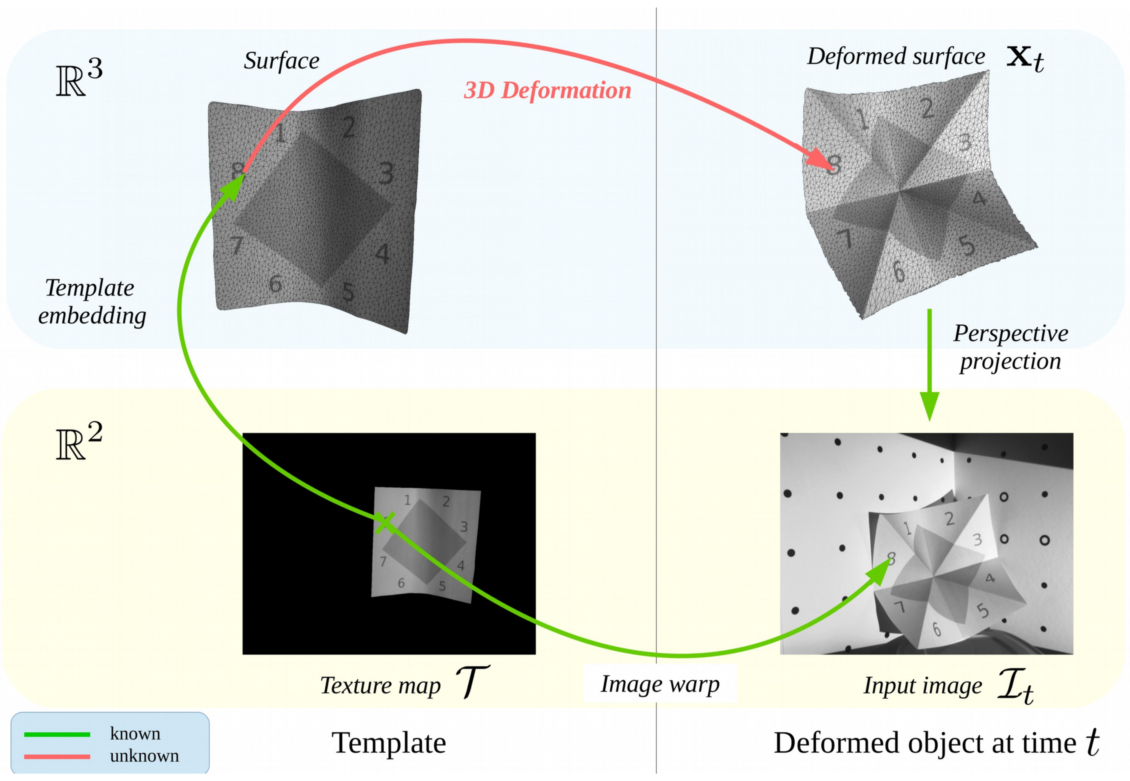
Contributions

Combining **SfT** and **shading**

(i) in a fully-integrated approach
(ii) to reconstruct complex deformations on all visible regions
(iii) without *any a priori* photometric calibration

Problem Modeling

Template Definition



Unknowns

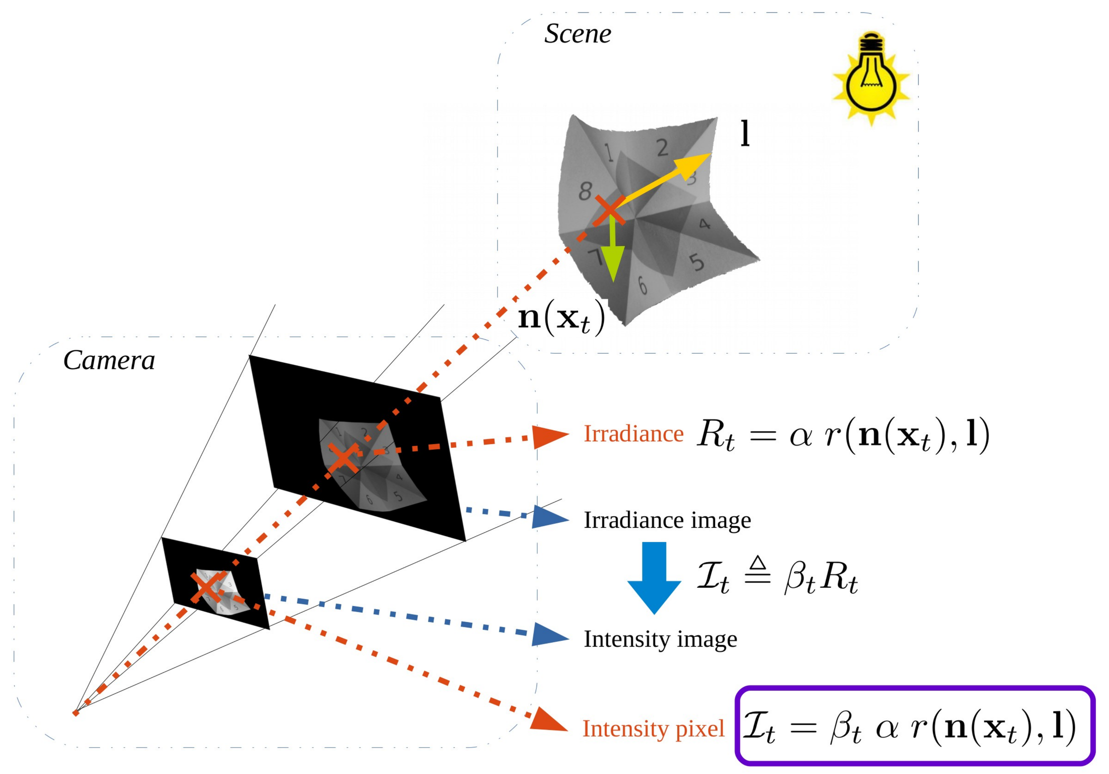
Deformation parameters $\mathbf{x}_1, \ldots, \mathbf{x}_N$

- Triangular regular dense mesh

Albedos $\alpha_1, \ldots, \alpha_K$

- Lambertian reflectance
- Piecewise constant albedos
- Computed from

Illumination and Camera Models



Shading equation

Illumination vector $\mathbf{l}$

- Fixed in camera coordinates
- Constant over time
- Spherical harmonics (4 and 9)

Camera responses $\beta_1, \ldots, \beta_N$

- Shutter speed and exposure
- Assumed linear
- Time-varying

Integrated Cost Function

Image Constraints	*Deformation Priors*
• Motion*	• Isometry
• Boundary*	• Smoothing*
• Shading*	

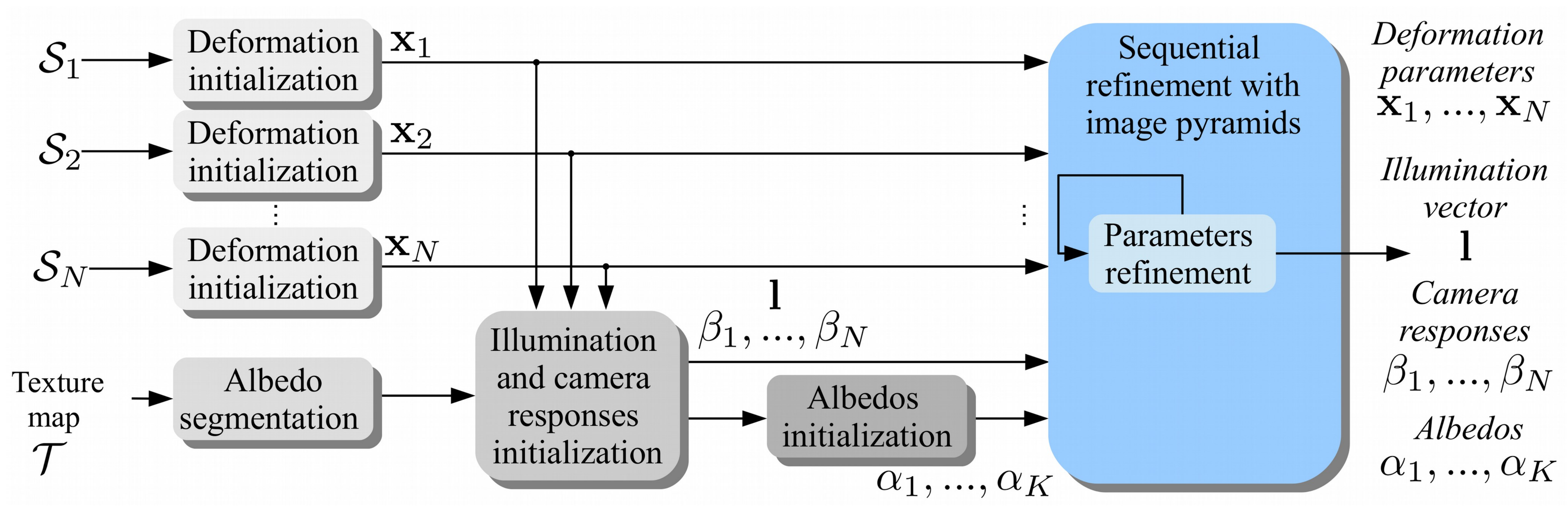
+

* *M-estimators* to robustify cost function: $(\ell_2 - \ell_1)$ and *Huber*

- to handle specularities and other unmodeled factors
- to allow piecewise smooth reconstructions
- to handle mis-matches and little contrast at edges surface

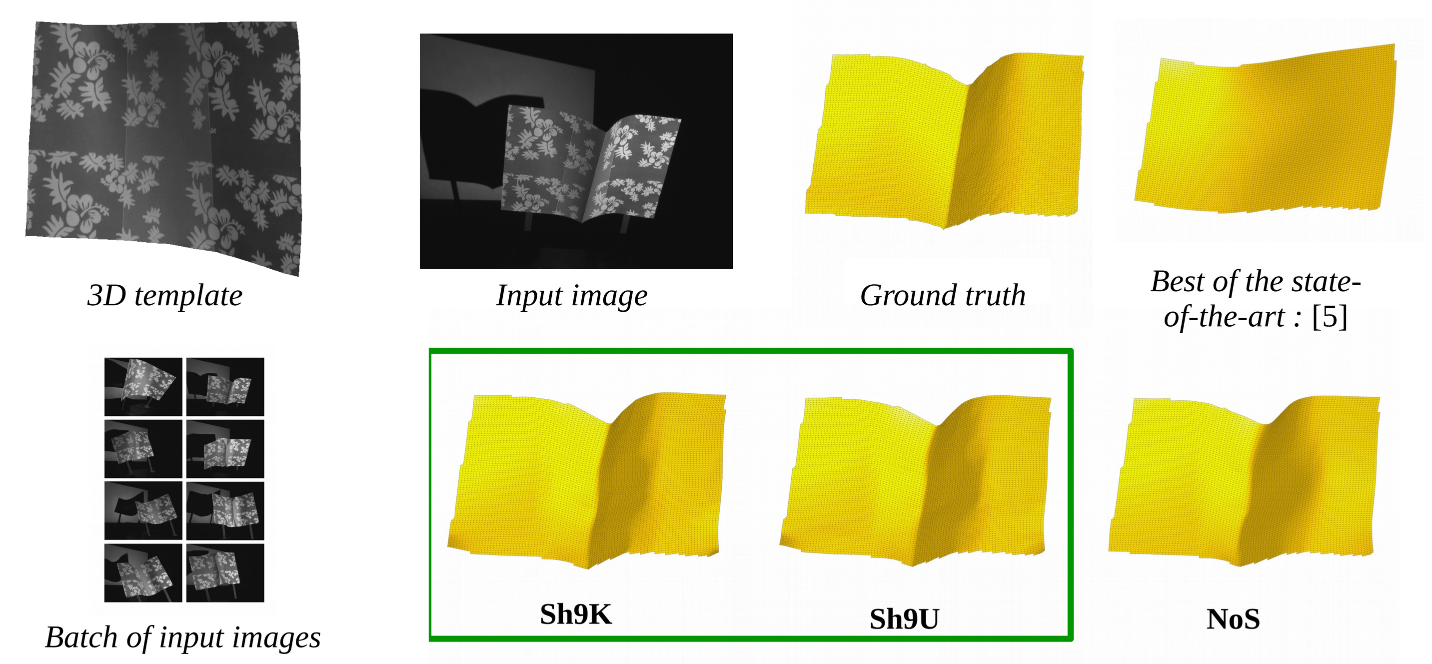
Strategy Solution

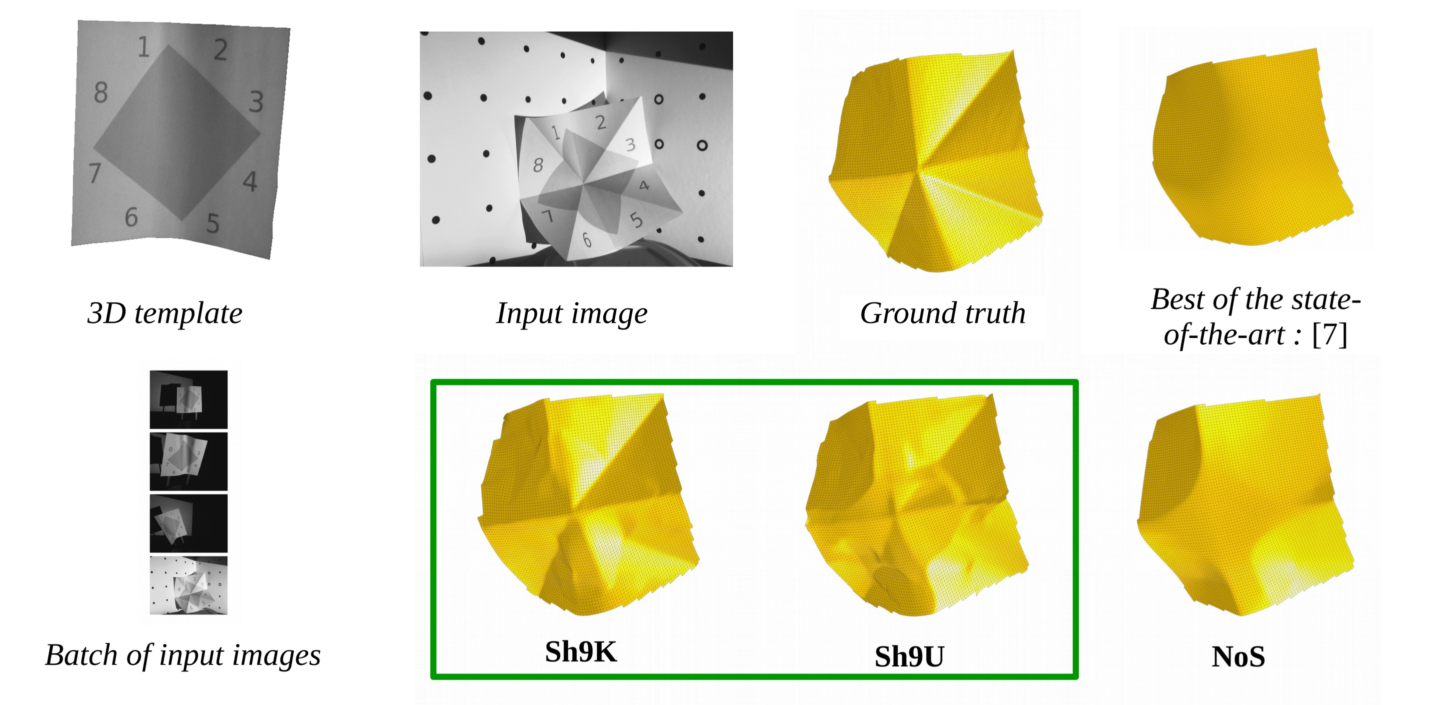
- Fast cascade **initialization** of deformation and photometric parameters
- Iterative gradient-based optimization to **refine** the integrated cost function (Gauss-Newton + backtracking line-searching + sparse Cholesky solver)
- Large sparse linear system (dense meshes of $\mathcal{O}(10^4)$ vertices)
- Batch of input images for shading equation: light, albedos constant over time



Results

- Real datasets with high-precision ground truth
- Comparison to SfT state-of-the-art: [4,5,6,7]
- Our methods: Sh9K (known light), Sh9U (unknown light) and NoS (without shading)
- Quantitative evaluations all over the surface and at the creases: 3D errors and normals





Better 3D reconstructions at creases and over the whole surface

References:
[1] Malti and Bartoli, TBME 2014
[2] Moreno-Noguer et al., CVPR 2009
[3] Varol et al., PAMI 2012
[4] Salzmann and Fua, PAMI 2011
[5] Bartoli et al., PAMI 2015
[6] Chhatkuli et al., CVPR 2014
[7] Ngo et al., PAMI 2016