Multiview Photometric Stereo using Planar Mesh Parameterization

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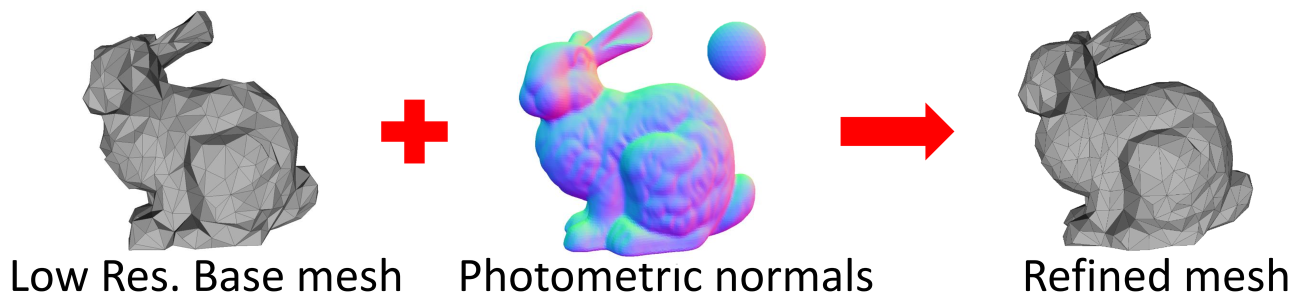
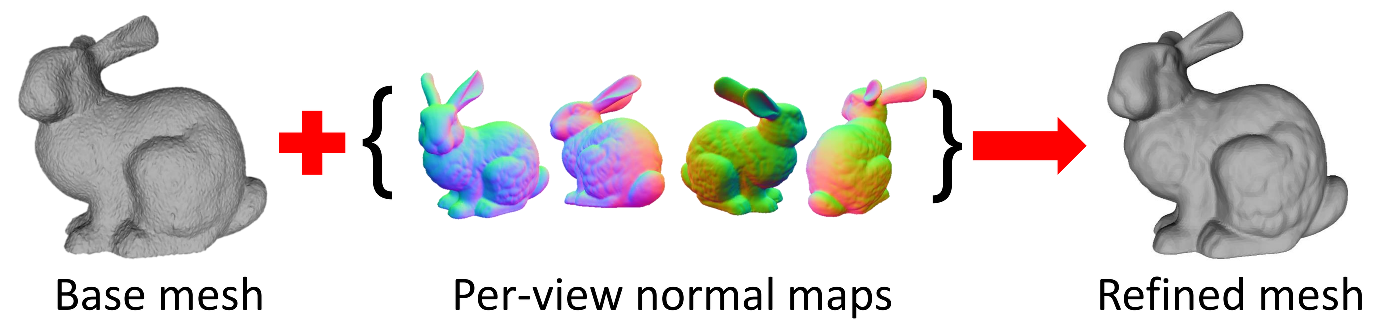
Challenges of Previous Methods

① Mesh based representations cannot fully utilize dense normals.

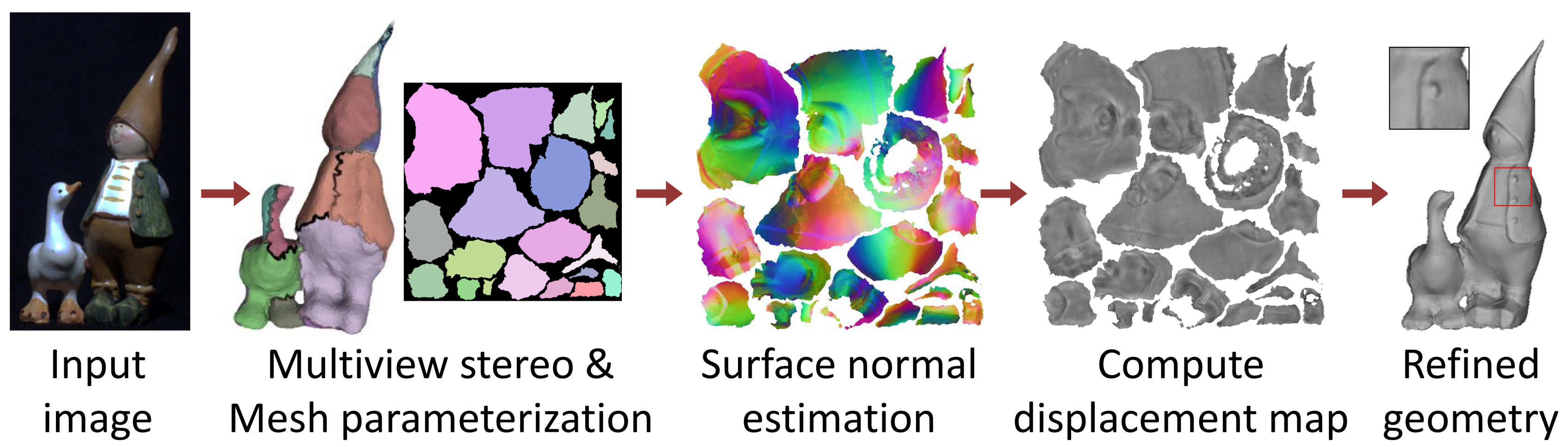


② Needs to merge per-view normal maps.



③ Uncalibrated lights → linear ambiguity

Overview of Our Approach



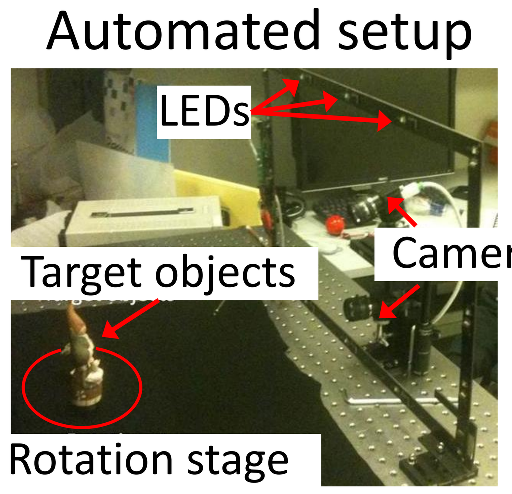
Key Contributions

- Images from multiple views are jointly handled
- Recover an extremely detailed 3D mesh exploiting the full resolution available in the input images.
- The optimization is more efficient than direct 3D methods [Hernández 08, Nehab 02] that must resort to subdividing the mesh and refining the vertex positions.

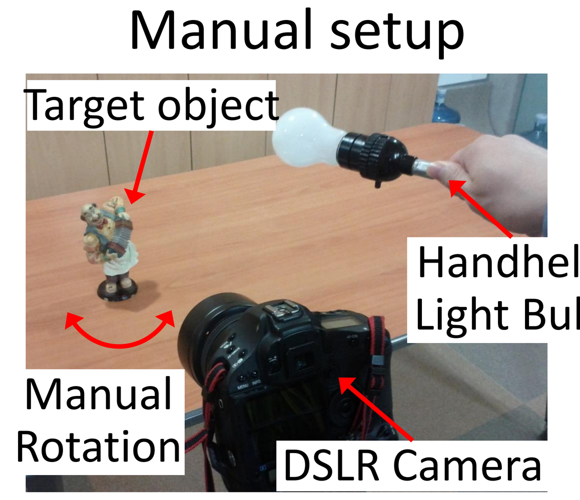
Imaging Setup

- For a particular rotation angle, several images are captured under varying lightings. (24 viewpoints, 15 degrees apart illuminated by 13 different LEDs – 312 images)
- Camera intrinsics are calibrated a priori

Automated setup



Manual setup



Preprocessing

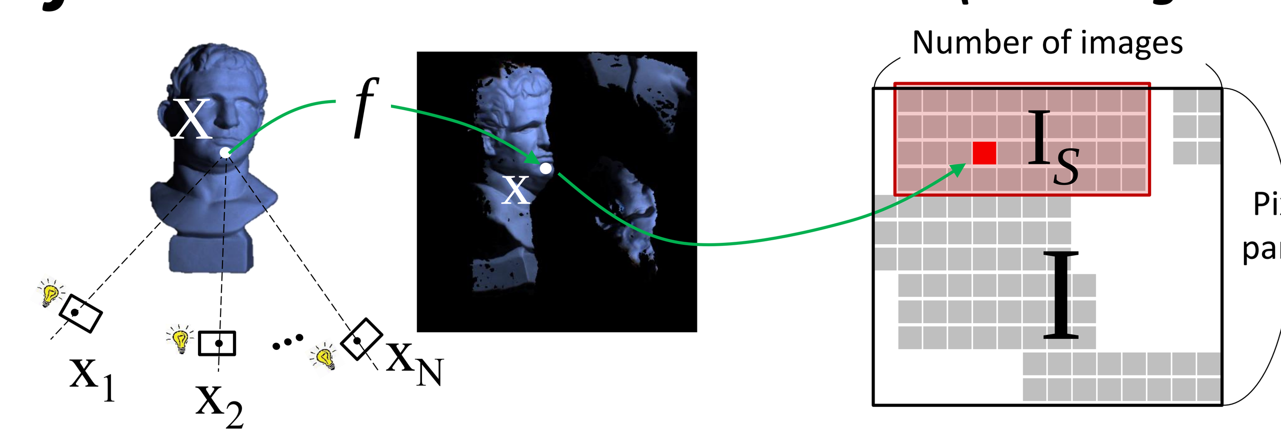
Base Mesh Acquisition

- Camera extrinsics are estimated using a generic SfM [Snavely 06]
- Plane-sweep stereo & volumetric graph cuts [Boykov 04]

Planar Mesh Parameterization & Image Warping

- We use the Iso-charts [Zhou 04], which minimizes non-uniform distortions of the original mesh
- Warp input images using inverse of parameterization function

Surface Normal Estimation (Handling linear ambiguity)



With rank 3 assumption [Hayakawa 94]

$$\mathbf{I}_S \approx \mathbf{U}_3\mathbf{\Sigma}_3\mathbf{V}_3^\top = \rho(\mathbf{N}_S\mathbf{A}^{-1})(\mathbf{A}\mathbf{L}_S) \quad (\mathbf{N}_S = \mathbf{U}_3\mathbf{\Sigma}_3^{\frac{1}{2}})$$

To resolve linear ambiguity

$$\mathbf{N}_S\mathbf{A}^{-1} \approx \underline{\mathbf{N}_f} = \mathbf{U}_3\mathbf{\Sigma}_3^{\frac{1}{2}}\mathbf{A}^{-1}$$

Surface normal from base mesh

Using pseudo inverse

$$\begin{cases} \mathbf{A} \leftarrow (\mathbf{N}_f^\top\mathbf{N}_f)^{-1}\mathbf{N}_f^\top\mathbf{U}_3\mathbf{\Sigma}_3^{\frac{1}{2}}, \\ \hat{\mathbf{N}}_S = \mathbf{U}_3\mathbf{\Sigma}_3^{\frac{1}{2}}\mathbf{A}^{-1} \end{cases}$$

(Uncalibrated photometric stereo)

Geometry Refinement

Vertices in parameterized space $\mathcal{U}$

$$\mathbf{x}^*(\mathbf{u}) = \mathbf{x}(\mathbf{u}) + d(\mathbf{u})\mathbf{n}_f(\mathbf{u})$$

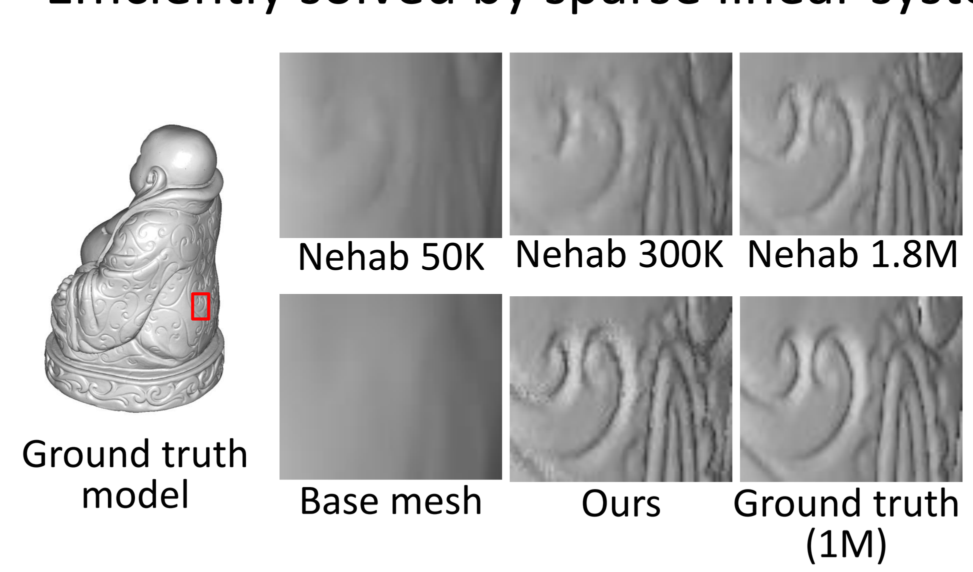
In order to get displacement d, we optimize

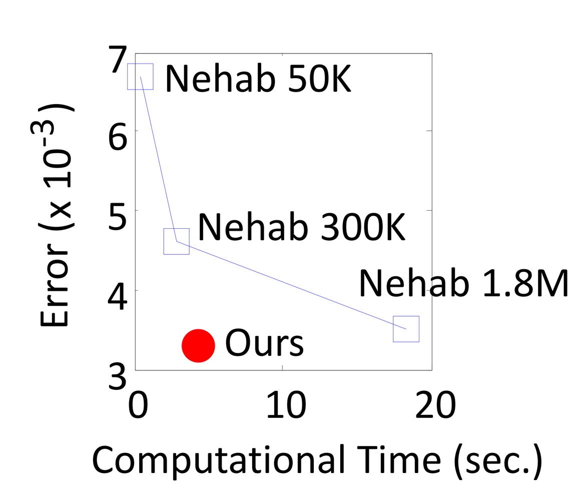
$$\hat{d} = \underset{d}{\operatorname{argmin}} \sum_{\mathbf{u}\in\mathcal{U}} \left(\mathbf{n}_p^\top \frac{\partial \mathbf{x}^*}{\partial \mathbf{u}}\right)^2 + \lambda \sum_{\mathbf{u}\in\mathcal{U}} d^2(\mathbf{u})$$

where $\mathbf{n}_p$ is photometric normal, $\mathbf{n}_f$ is face normal.

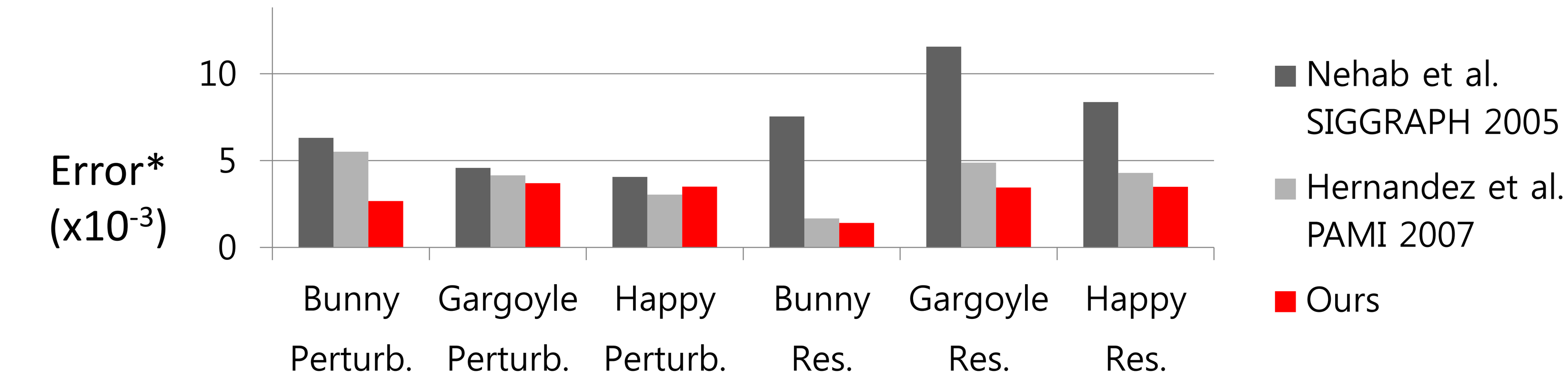
Computational Benefits

- Optimizing a single scalar *d* instead of three coordinates
- Efficiently solved by sparse linear system



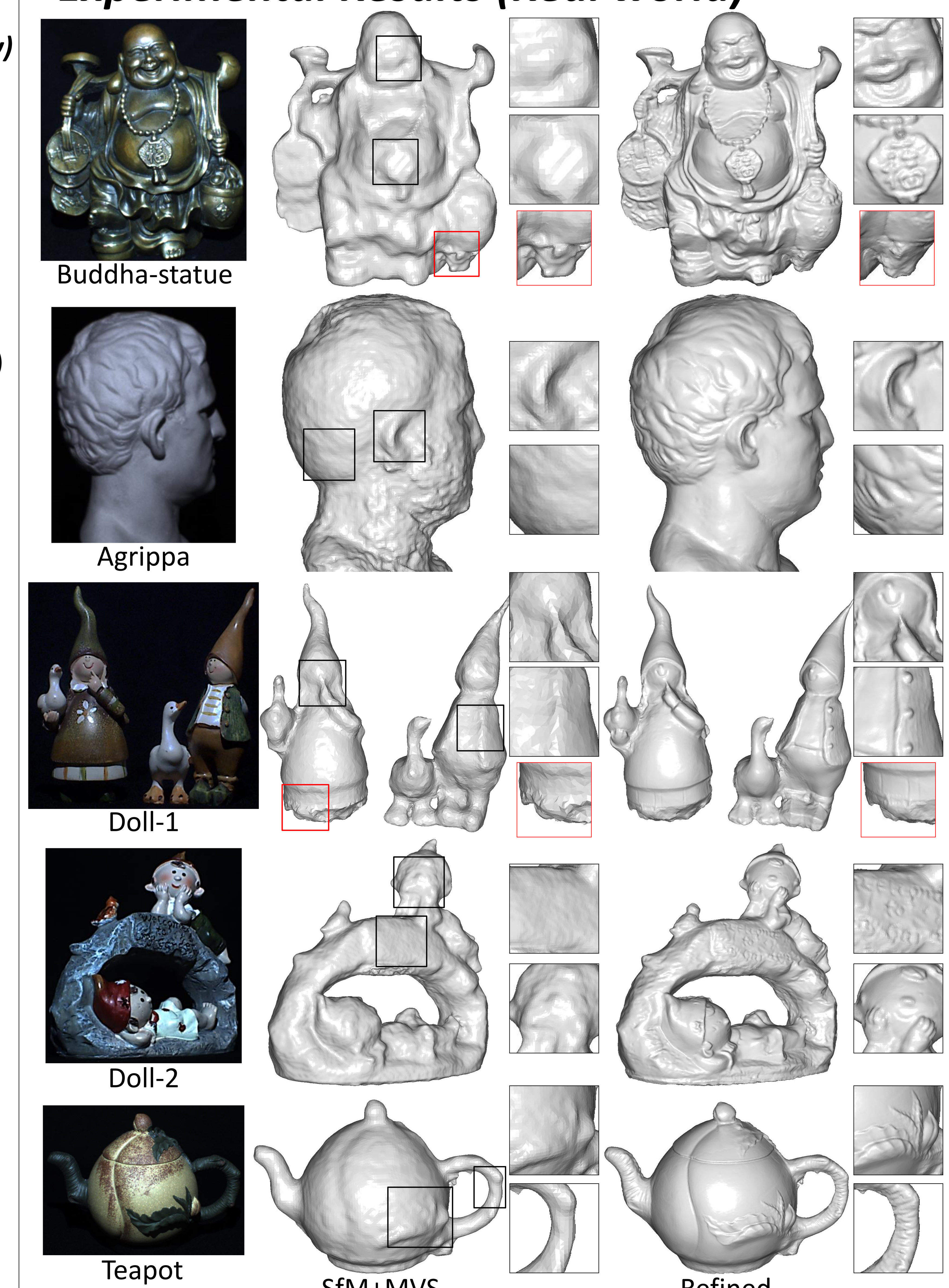


Experimental Results (Synthetic)



*Error is the distance which is bigger than 90% of distances to the ground-truth

Experimental Results (Real world)



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