Angular Domain Reconstruction of Dynamic 3D Fluid Surfaces

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The Problem

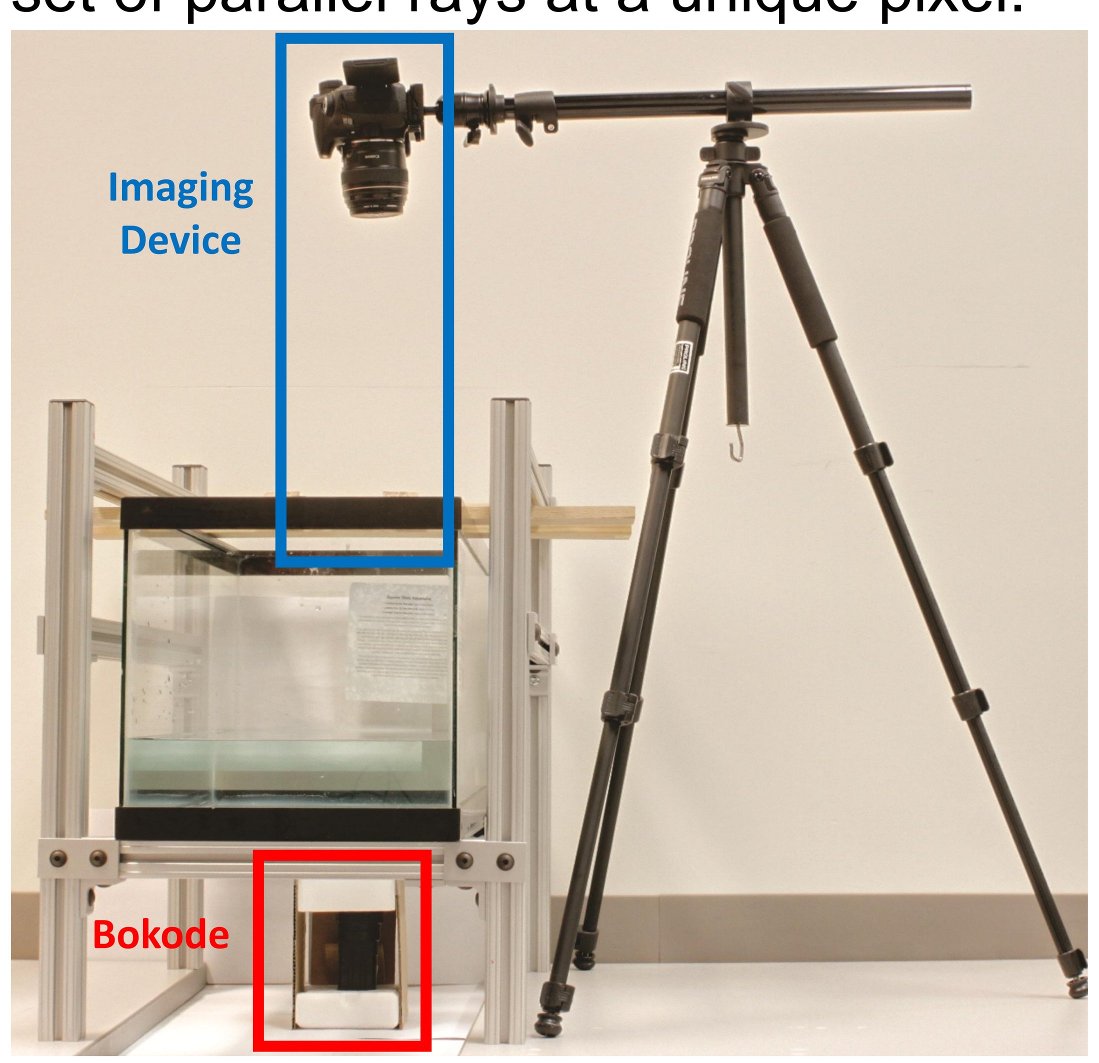
- Reconstruct dynamic 3D fluid surface[1].
- Traditional point-pixel correspondences lead to height ambiguity.
- We resolve the ambiguity by establishing ray-ray correspondences.

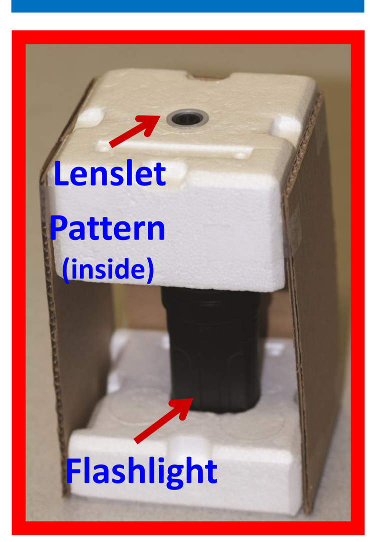
Key Contributions

- A complete computational imaging solution for acquiring dynamic specular surfaces.
- We obtain ray-ray correspondences through a fluid surface via a Bokode[2] – Camera pair.
- We derive a new surface integration scheme in the angular domain to reconstruct the surface from the angularly sampled normal field.

Acquisition Device

- Each point on the Bokode pattern maps to a beam of parallel rays.
- These rays are refracted by the fluid surface and alter directions.
- The view camera focuses at infinity to capture each set of parallel rays at a unique pixel.

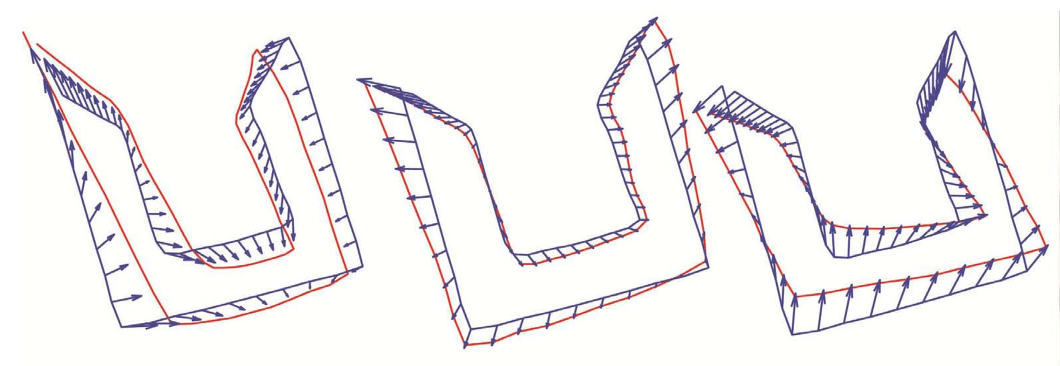




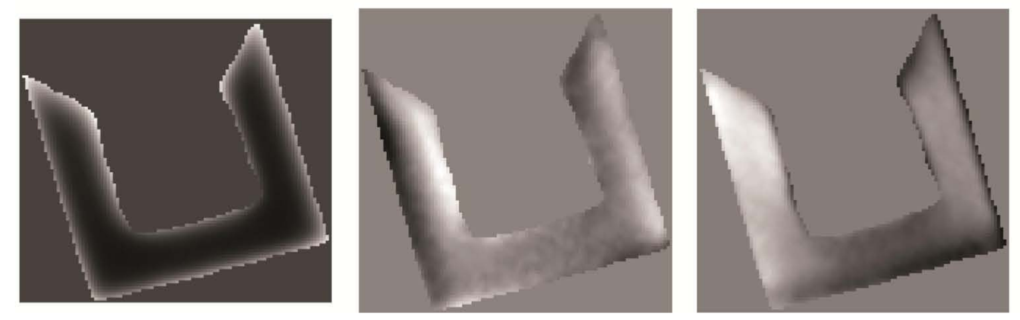
(Note: We use an auxiliary bi-convex lens to collect more refracted light.)

Reconstruction Algorithm

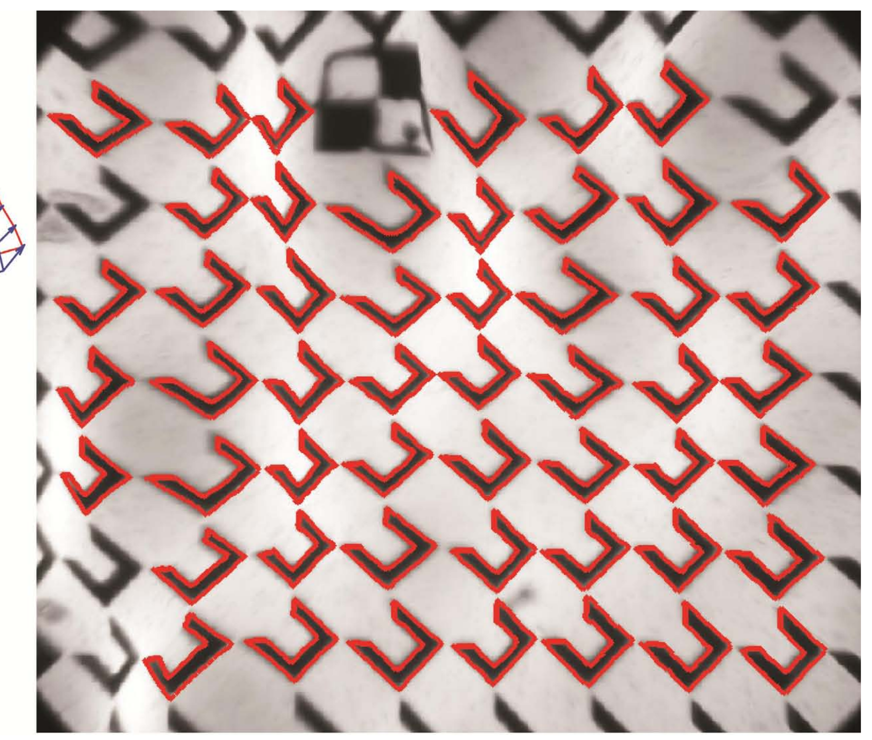
1. Robust Feature Matching via Active Appearance Model(AAM)



AAM shape model



AAM appearance model



An example of AAM matched pattern

2. Obtain Ray-Ray Correspondences

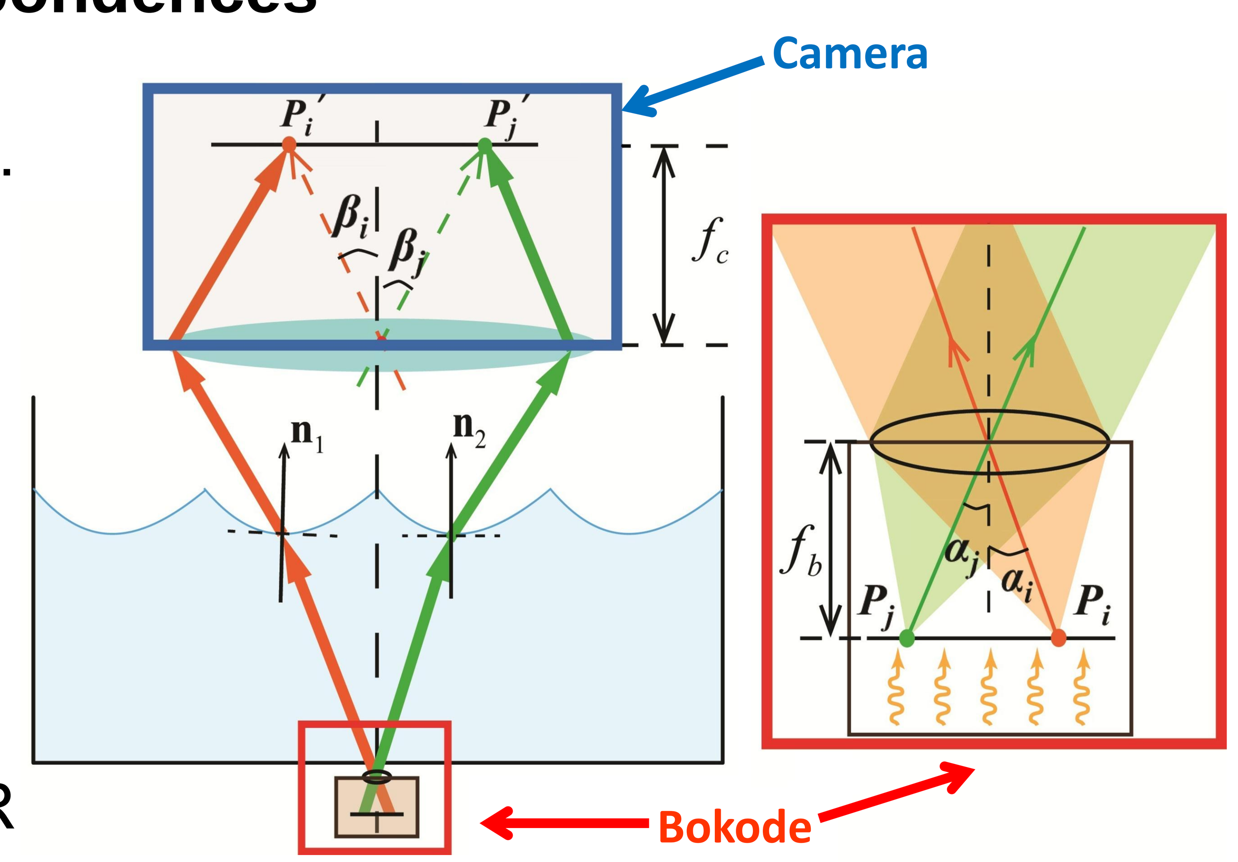
- $P_i(x_i, y_i)$ and $P'_i(x'_i, y'_i)$ are corresponding feature points.
- Incident ray (IR) direction:

$$\alpha_i = \arctan(\sqrt{x_i^2 + y_i^2}/fb)$$

- Exit ray (ER) direction:

$$\beta_i = \arctan(\sqrt{x'^2_i + y'^2_i}/fc)$$

- Calculate normal $\mathbf{n}$ using IER correspondences.



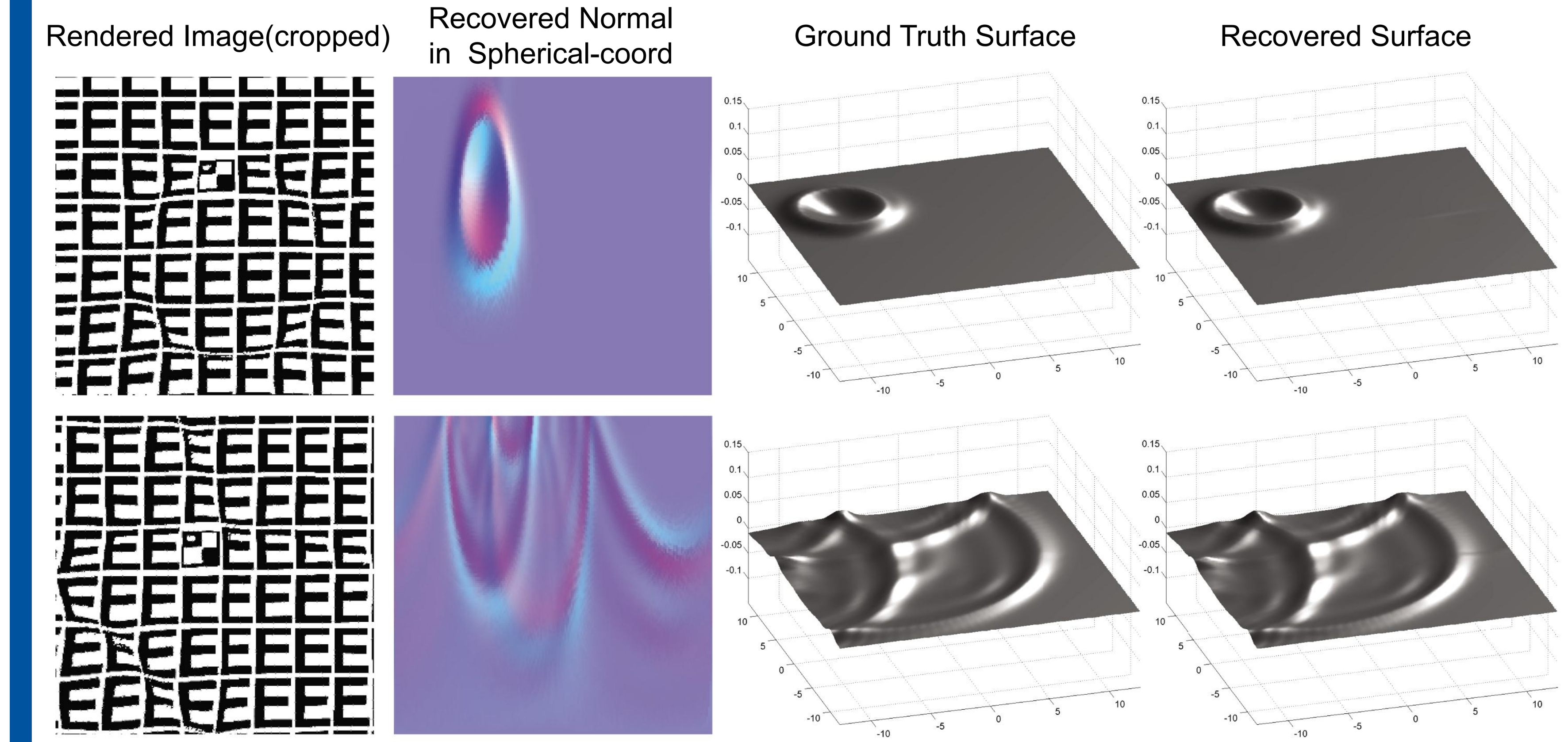
3. (Angular) Normal Estimation and Integration:

- The imaging system recovers an angularly sampled normal field.
- Parameterize the surface in spherical coordinates as $r(\theta, \phi)$.
- Formulate normals measured in Cartesian coordinate to spherical coordinate gradients: (Eqn.(1)).
- Discretize Eqn. (1) to form an over-constrained linear system.

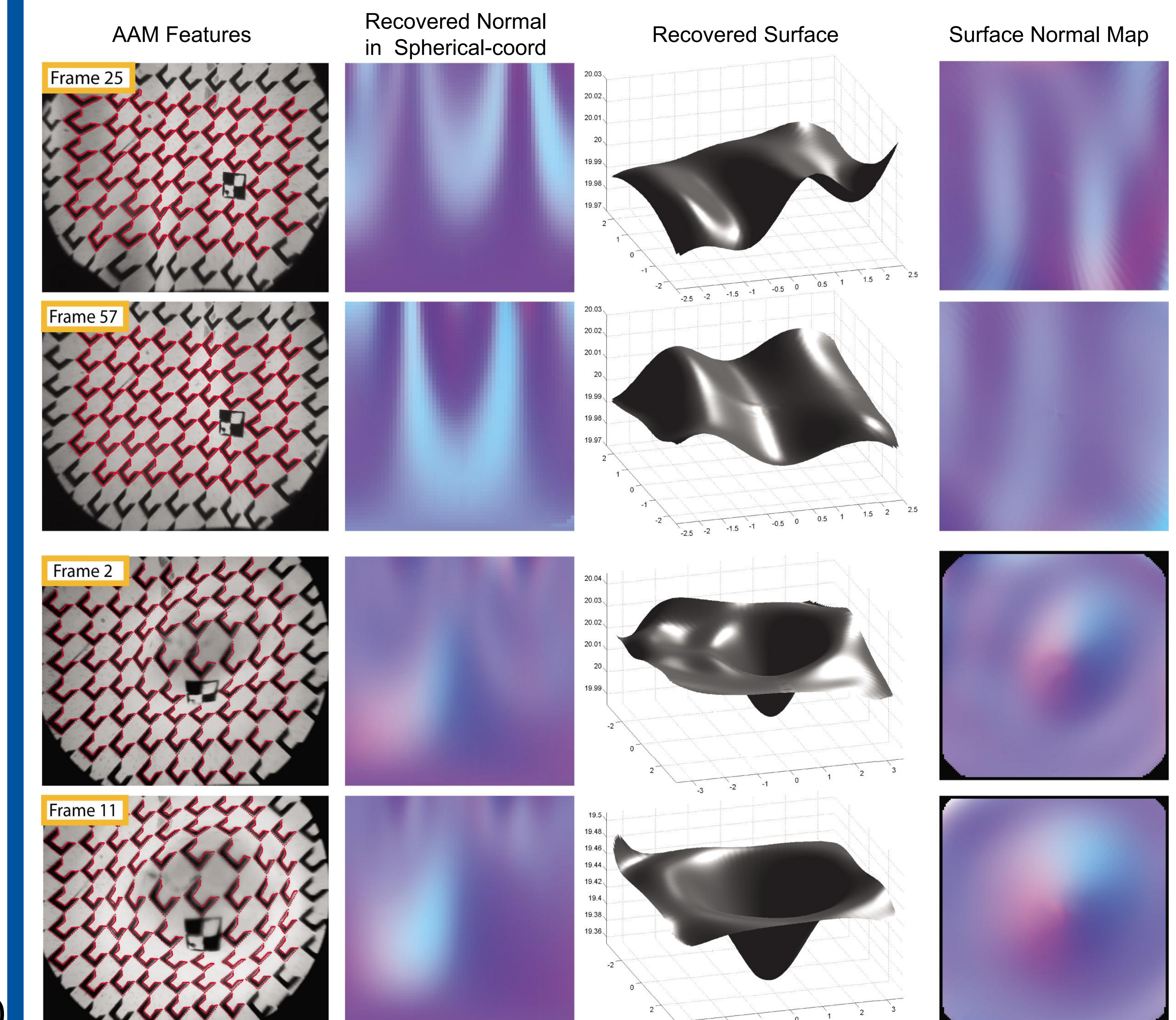
$$\begin{cases} \dfrac{\partial r}{\partial \theta} = r \cdot \dfrac{\sin\phi(\frac{\partial z}{\partial x}\sin\theta - \frac{\partial z}{\partial y}\cos\theta)}{\sin\phi(\frac{\partial z}{\partial x}\cos\theta + \frac{\partial z}{\partial y}\sin\theta) - \cos\phi} \\ \dfrac{\partial r}{\partial \phi} = r \cdot \dfrac{\sin\phi + \cos\phi(\frac{\partial z}{\partial x}\cos\theta + \frac{\partial z}{\partial y}\sin\theta)}{\cos\phi - \sin\phi(\frac{\partial z}{\partial x}\cos\theta + \frac{\partial z}{\partial y}\sin\theta)} \end{cases} \quad (1)$$

- Also proved that classical Poisson can also be formulated as such.

Results on Synthetic Surfaces



Results on Real Water Surfaces



Reference:

[1] N. Morris and K. Kutulakos. Dynamic refraction stereo. In *ICCV*, 2005

[2] A. Mohan, G. Woo, S. Hiura, Q. Smithwick, and R. Raska. Bokode: imperceptible visual tags for camera based interaction from a distance. In *SIGGRAPH*, 2009

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