Reconstruction *in the round* with Photometric Normals

George Vogiatzis,
Carlos Hernandez Esteban,
Roberto Cipolla
Uniform albedo Lambertian objects (with highlights)

- Challenging objects
- Lack of features makes correspondences hard
- **Silhouette** and **shading** are only available cues
Photometric stereo

- Single Viewpoint
- Move light-source for each image
- Same pixel always corresponds to same surface point
- With known light directions can estimate $n$
- Integrate normals to get depth map

$$i = l^T n$$
Photometric stereo

- To get more than depth-maps, we need **multiple-viewpoints**…
- … and in that case pixels are no longer automatically in correspondence
- However, if some correspondence is given, photometric stereo can proceed as usual

- Our strategy:
  1. Estimate light directions & intensities
  2. Evolve a surface using photometric stereo with approximate correspondences from the current surface (starting from visual hull)
1. Light estimation

- Three surface points with known surface normals and their image intensities are enough to estimate a directional light source.

\[ l = \left[ n_a \ n_b \ n_c \right]^{-1} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \]

- But where do you get these three points?
1. Light estimation

- Answer: From the visual hull
1. Light estimation
1. Light estimation

- Recover generators by random sampling
Accuracy of light estimation
1. Light estimation
2. Multi-view photometric stereo

- Mesh with vertices $x_1, \ldots, x_M$
- And faces $f=1, \ldots, F$
- Define photometric normals $v_1, \ldots, v_F$
- Minimise sum of two energies
  - $E_m$ with respect to $x_1, \ldots, x_M$
  - $E_v$ with respect to $v_1, \ldots, v_F$

\[
E_m (x_1, \ldots, x_M; v_1, \ldots, v_F) = \sum_{f=1}^{F} \| n_f - v_f \|^2 A_f
\]

\[
E_v (v_1, \ldots, v_F; x_1, \ldots, x_M) = \sum_{f=1}^{F} \sum_{k \in V_f} (l_k^T v_f - i_{f,k})^2
\]
2. Multi-view photometric stereo

- evolution

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Mesh Evolution
Full algorithm for uniform objects

Capture images of object.
Extract silhouettes.
Recover camera motion and compute visual hull.
Estimate light directions and intensities in every image.

Initialise a mesh with vertices $x_1 \ldots x_M$ and faces $f = 1 \ldots F$ to the object’s visual hull.

while mesh-not-converged do
    Optimise $E_v$ with respect to $v_1 \ldots v_F$.
    Optimise $E_m$ with respect to $x_1 \ldots x_M$.
end while
Results
Results
Results
Results
Results – Fitzwilliam museum
Results – Fitzwilliam museum
Results – Fitzwilliam museum
Results – Fitzwilliam museum
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Buddha

- For multi-albedo objects the technique can improve the results of state-of-the-art correspondence based techniques e.g. [Hernandez et al 2004]

Multi-view Dense Stereo
[Hernandez et al 2004]

Multi-view Photometric Stereo
Results – Fitzwilliam museum

Buddha

• For multi-albedo objects the technique can improve the results of state-of-the-art correspondence based techniques e.g. [Hernandez et al 2004]