Photometric 3D-reconstruction: Towards industrial applications

Colloquium Maurizio’60

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IRIT, Toulouse
1. Shape-from-X techniques
2. Photometric techniques
3. Shape-from-shading
4. Photometric stereo
Outline

1. Shape-from-X techniques
2. Photometric techniques
3. Shape-from-shading
4. Photometric stereo
3D-scanning \neq 3D-reconstruction

3D-scanning \equiv 3D-reconstruction + Color estimation

Some applications of 3D-reconstruction
- Architecture
- Cultural heritage
- Metrology
- Augmented reality

Different kinds of 3D-reconstruction techniques
- Palpation \equiv Mechanical process
- Telemeters \equiv Time of flight of laser pulses
- Kinect \equiv Projection of an infra-red pattern
- Photographic techniques \equiv Shape-from-X
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- Metrology $\Rightarrow$ In our laboratory
- Augmented reality $\Rightarrow$ In our laboratory

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### Shape-from-X techniques

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Basic principle of the photometric techniques

Data provided by an atomic force microscope (AFM)

Depth map (Kinect)  Image (camera)

Paradox of the human vision

- Depth map = Solution of the 3D-reconstruction problem
- We better infer the 3D-shape from the image!
Image model: make your choice

Image $\equiv$ Scene + Light + Camera

Assumption on the scene
- Simplest: Lambert (purely diffusing)
- More complex: Phong, Blinn (diffusing and specular)

Assumption on the light
- Simplest: parallel and uniform (vector $S$)
- More complex: nearby source

Assumption on the camera
- Simplest: orthographic
- More complex: perspective
Photometric techniques

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Simplest image model

Simplest assumptions
- Scene: Lambert (purely diffusing)
- Light: parallel and uniform (vector $S$)
- Camera: orthographic

Simplest non-differential model
- Relation between graylevel $I$, albedo $\rho$ and normal $N$:
  \[ I = \rho \, N^\top \, S \quad (1) \]
- Relation between normal $N$ and depth $u$:
  \[ N = 1/\sqrt{u_x^2 + u_y^2 + 1} \, [-u_x, -u_y, 1]^\top \quad (2) \]

Simplest differential model
- $(1) + (2) \Rightarrow I = \rho \left( -S_1 u_x - S_2 u_y + S_3 \right) / \sqrt{u_x^2 + u_y^2 + 1} \quad (3)$
- Non-linear PDE in $u$
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Shape-from-shading

Even simpler image model

Additional assumptions

- \( n = 1 \) image \( \Rightarrow \) Shape-from-shading (SFS)
- Frontal light: \( S = [0, 0, 1]^\top \) \( \Rightarrow \) No shadow
- Known albedo: \( \rho \equiv 1 \)

Simplest non-differential SFS model

- \((1) \Rightarrow I = N^\top S\)
- Scalar product \( N^\top S \): called “shading”

Simplest differential SFS model

- \((3) \Rightarrow |\nabla u|^2 = \frac{1}{I^2} - 1\)
- Eikonal equation \( \Rightarrow 50\% \) of the papers on SFS
### Resolution of the eikonal equation

<table>
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<th>Method</th>
<th>Boundary Condition Required</th>
<th>Solution Type</th>
<th>Code Difficulty</th>
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<td>PDE approach [Falcone and Sagona, ICIAP 1997]</td>
<td>Yes</td>
<td>Exact solution</td>
<td>Hard</td>
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<td>Optimisation approach [Daniel and Durou, ACCV 2000]</td>
<td>No</td>
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<td>Linearization of the model [Tsai and Shah, CVPR 1992]</td>
<td>Yes</td>
<td>Approximated solution</td>
<td>Easy</td>
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Simple model or simplistic model?

PDE approach (Falcone and Sagona)

Initial image  
Reconstructed shape  
Recomputed image
Simple model or simplistic model?

Optimisation approach (Daniel and Durou)

Initial image
Reconstructed shape
Recomputed image
Simple model or simplistic model?

Linearization of the model (Tsai and Shah)

Initial image  
Reconstructed shape  
Recomputed image
More realistic image models

Assumption on the scene
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- More complex: nearby source

Assumption on the camera
- Simplest: orthographic
- More complex: perspective

But similar results, because SFS is ill-posed
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Photometric stereo (PS): example of data

Simplest image model

\[ l^i = \rho N^T S^i, \quad i = 1, 2, 3 \]
Photometric stereo

Photometric stereo (PS): example of results

- Shape $\Rightarrow$ Visually satisfactory
Photometric stereo (PS): example of results

- Shape ⇒ Visually satisfactory
- Albedo ⇒ Should be uniform
Photometric stereo (PS): example of results

- Shape ⇒ Visually satisfactory
- Albedo ⇒ Should be uniform ⇒ Refine the image model
Our compromise between realism and tractability

Assumption on the scene
- **Simplest:** Lambert (purely diffusing)
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Photometric stereo: three recent applications

Virtual glasses trying
- Augmented reality + Metrology
- Industrial application
- Fitting Box company, Toulouse

Dermatological and cosmetic studies
- Metrology
- Industrial application
- Pixience company, Toulouse

3D-scanning from screen-watching
- Augmented reality
- Multimedia application
Conclusion and Perspectives

Importance of the number $n$ of images

- Case $n = 1$ (SFS) $\Rightarrow$ Ill-posed problem
- Case $n \geq 3$ (PS) $\Rightarrow$ Well-posed problem
- Intermediate case $n = 2$ (PS2) $\Rightarrow$ cf. Roberto Mecca’s talk

Photometric stereo (PS): some tricks towards applications

- Lambert’s law is not realistic:
  Many outliers (shadows, etc.), but $n \approx 20$ $\Rightarrow$ Robustness
- Light model is crucial (nearby sources):
  Augmented reality (qualitative) $<\!\!<$ Metrology (quantitative)

Perspectives

- More realistic scene model $\Rightarrow$ cf. Silvia Tozza’s talk
- Real-time PS: the scene does not have to be fixed anymore