Photometric 3D-reconstruction: Towards industrial applications

Colloquium Maurizio'60

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Outline

1. Shape-from-X techniques
2. Photometric techniques
3. Shape-from-shading
4. Photometric stereo

Outline

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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Shape-from-X techniques

	Geometric techniques	Photometric techniques
Mono-view techniques ($n = 1$ image)	Shape-from-structured light Shape-from-shadow Shape-from-contour Shape-from-texture	Shape-from-shading
Multi-view techniques ($n > 1$ images)	Stereoscopy Structure-from-motion Shape-from-silhouettes Shape-from-defocus	Photometric Stereo

Shape-from-X techniques

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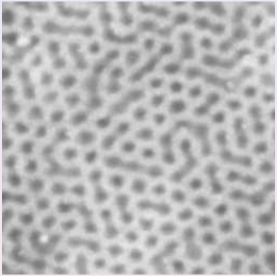
Basic principle of the photometric techniques

Data provided by an atomic force microscope (AFM)



Depth map (Kinect)

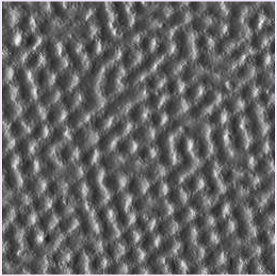


Image (camera)

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

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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 ρ and normal N:
  $I = \rho N^\top S$ (1)
- Relation between normal N and depth u:
  $N = 1/\sqrt{{u_x}^2 + {u_y}^2 + 1}\ [-u_x, -u_y, 1]^\top$ (2)

Simplest differential model

- (1) + (2) $\Rightarrow$ $I = \rho\,(-S_1 u_x - S_2 u_y + S_3)/\sqrt{{u_x}^2 + {u_y}^2 + 1}$ (3)
- Non-linear PDE in u

Outline

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) $\Rightarrow |\nabla u|^2 = \dfrac{1}{I^2} - 1$
- Eikonal equation $\Rightarrow$ 50% of the papers on SFS

Resolution of the eikonal equation

PDE approach [Falcone and Sagona, ICIAP 1997]

- Boundary condition required
- Exact solution
- Not easy to code

Optimisation approach [Daniel and Durou, ACCV 2000]

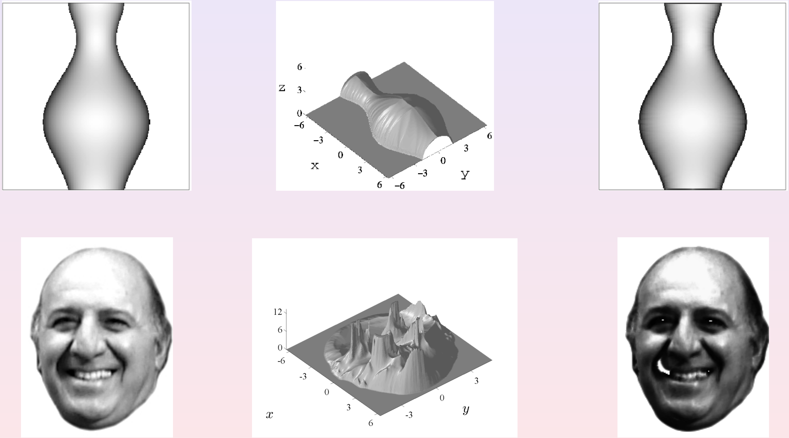
- Boundary condition not required
- Approximated solution
- Not easy to code

Linearization of the model [Tsai and Shah, CVPR 1992]

- Boundary condition required
- Approximated solution
- Easy to code

Simple model or simplistic model?

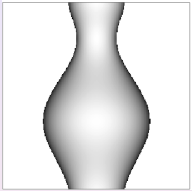
PDE approach (Falcone and Sagona)

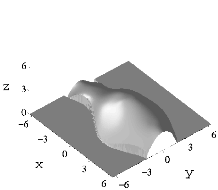


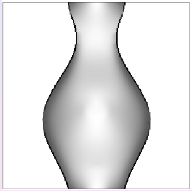
Initial image | Reconstructed shape | Recomputed image

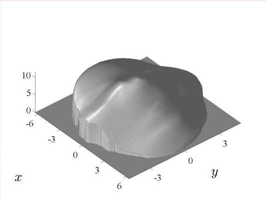
Simple model or simplistic model?

Optimisation approach (Daniel and Durou)









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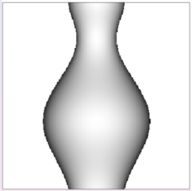
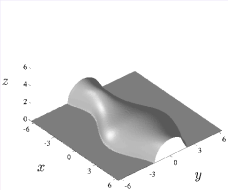
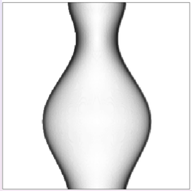
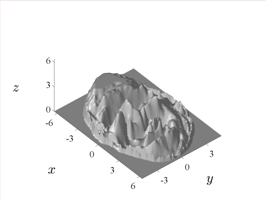
Simple model or simplistic model?

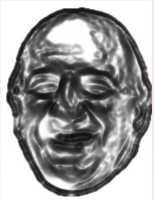
Linearization of the model (Tsai and Shah)











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More realistic image models

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Assumption on the camera

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But similar results, because SFS is ill-posed

Outline

Photometric stereo (PS): example of data

S^1

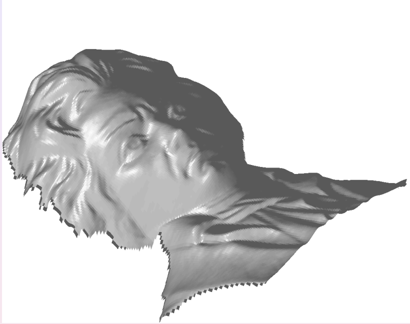
S^2

S^3

Simplest image model

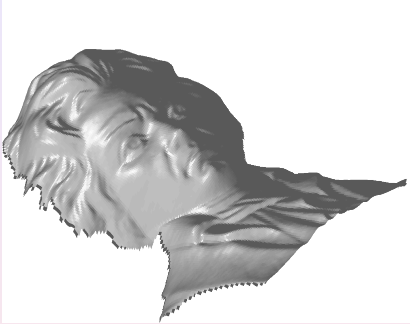
$$I^i = \rho N^\top S^i, \qquad i = 1, 2, 3$$

Photometric stereo (PS): example of results



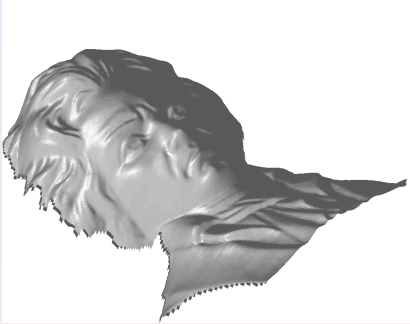
- Shape ⇒ Visually satisfactory
-

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

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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