3D Reconstruction

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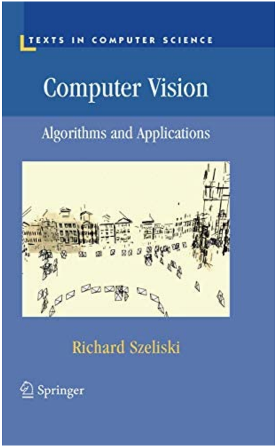
Overview

Book Reference



Chapter 12 at *Computer Vision: Algorithms and Applications*. Richard Szeliski. September 3, 2010 draft.[1] © 2010 Springer

[1] https://szeliski.org/Book/drafts/SzeliskiBook_20100903_draft.pdf

Shape from X

Question

How we infer the shape?

- Shape from *shading*
- Shape from *texture*
- Shape from *focus*

Shape from Shading

Shading of the objects helps inference of the shape!

Figure: Synthetic shape from shading (Zhang, Tsai, Cryer et al. 1999) © 1999 IEEE

Irradiance Equation

$$I(x,y) = R(p(x,y), q(x,y)) \tag{1}$$

where,

- $(p; q) = (zx; zy)$ are the depth map derivatives
- $R(p; q)$ is called the reflectance map

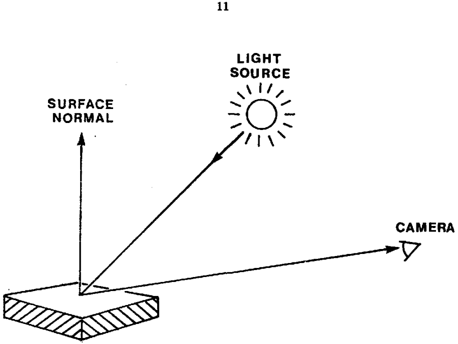


Figure: Depiction of irradiance surface orientation

Photometric Stereo

- Multiple light sources that can be selectively turned on and off
- For each light source, we have a different reflectance map $R_1(p, q)$, $R_2(p, q)$, ...

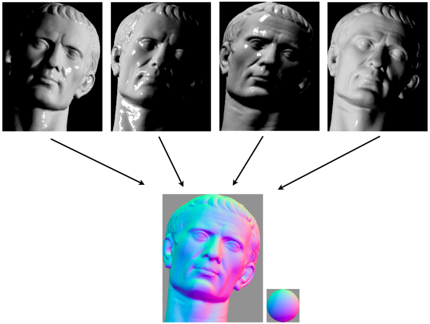


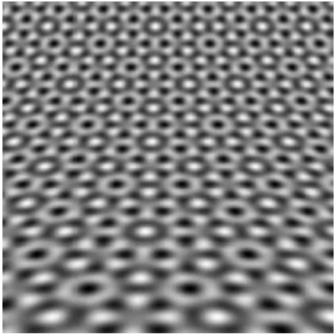
Figure: Shaded images from different directions and corresponding shape from shading reconstructions

Shape From Texture

Requires a number of processing stages

1. extraction of repeated patterns
2. measurement of local frequencies
3. infer local surface orientation

Shape From Texture


(a)

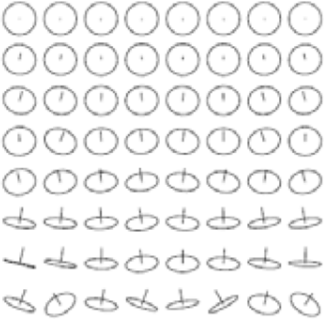

(b)

Figure: Synthetic shape from texture (Garding 1992) © 1992 Springer: (a) regular texture wrapped onto a curved surface and (b) the corresponding surface normal estimates.

Shape from Focus

A number of techniques have been developed to estimate depth from the amount of defocus

- use two or more images captured with different focus distance settings
- using telecentric optics that utilize varying magnification of the object
- usage of rational filters to reliably estimate the amount of defocus

Shape from Focus

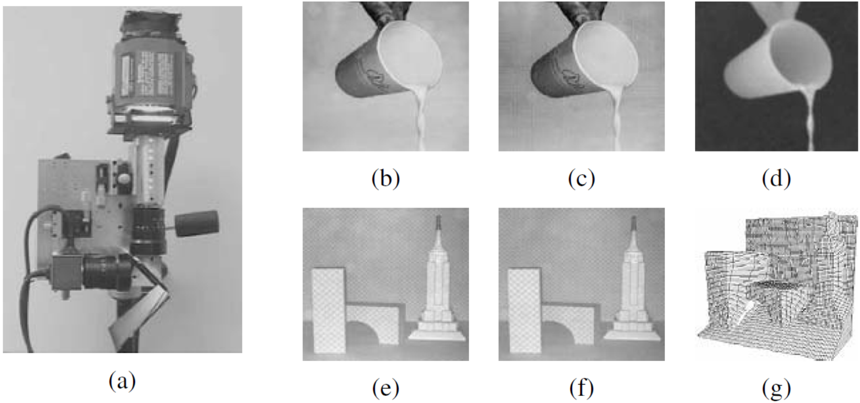


Figure: Real time depth from defocus (Nayar, Watanabe, and Noguchi 1996) © 1996 IEEE

Active Rangefinding

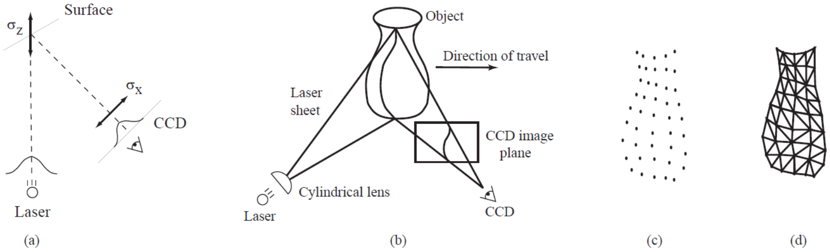
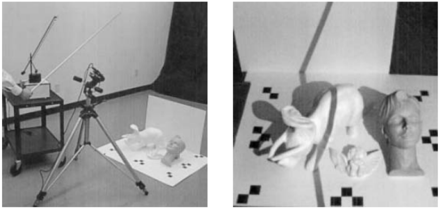


Figure: Range data scanning (Curless and Levoy 1996) © 1996 ACM

Active Rangefinding

Waving a stick casting shadow over an object or scene

- shadow falls across planes
- plane equation for each stripe can be inferred
- may also be used to estimate the 3D geometry of a background scene



(a) (b)

Figure: Shape scanning using cast shadows (Bouguet and Perona 1999) © 1999 Springer

Active Rangefinding

Also possible for real-time scenes!

Figure: Real-time dense 3D face capture using spacetime stereo (Zhang, Snavely, Curless et al. 2004) © 2004 ACM

Range Data Merging

Modern applications are more complex!

1. Individual range images (we've seen so far)
2. Registration (alignment) of partial 3D surface models
3. Integration into coherent 3D surfaces

Volumetric Range Image Processing (VRIP)

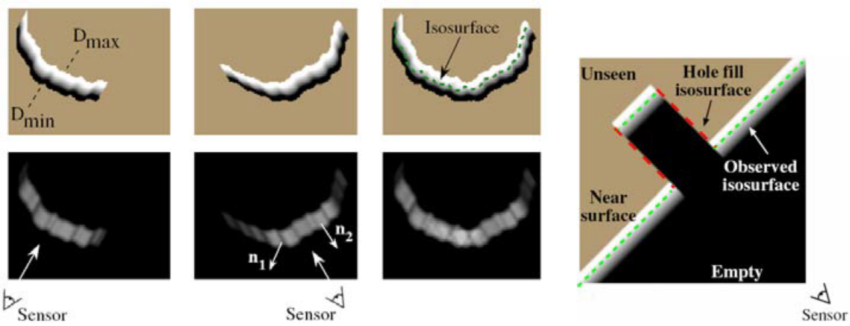


Figure: Range data merging (Curless and Levoy 1996) © 1996 ACM

Surface Representations

Surface Interpolation
reconstruction from a set of sparse data constraints, i.e. scattered data interpolation

surfaces may be parameterized as

- height fields $f(x)$
- 3D parametric surfaces $\mathbf{f}(x)$
- non-parametric models such as collections of triangles

note: it is assumed that the topology of the surface is known and fixed ahead of time!

Surface Simplification

- hierarchy of mesh models
- displayed *level of detail* (LOD)

Different approaches such as

- subdivision connectivity
- edge collapse operations

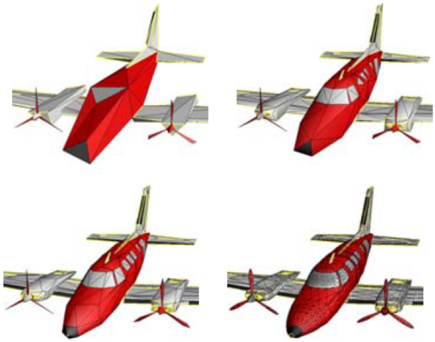


Figure: Progressive mesh representation of an airplane model (Hoppe 1996) © 1996 ACM

Surface Representations

Geometric Images

To make the triangulation completely regular (uniform and gridded), Gu, Gortler, and Hoppe (2002) describe how to create geometry images

Cutting surface meshes along well chosen lines and "flattening" the resulting representation into a square

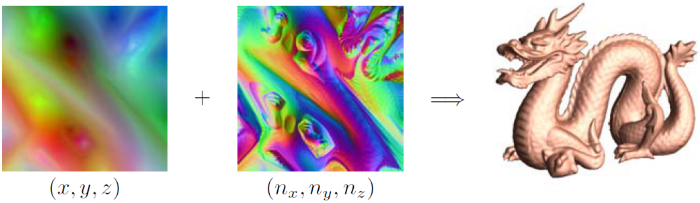


Figure: Geometry images (Gu, Gortler, and Hoppe 2002) © 2002 ACM

Point-based Representations

- Let triangle vertices behave as **oriented points**
- A soft influence function is used to couple nearby particles

render the particle system as a continuous surface

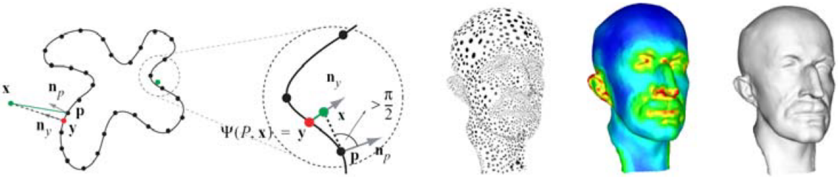
- local dynamic triangulation heuristics[2]
- direct surface element splatting[3]

or convert point cloud into an implicit signed distance or inside–outside function

Even greater precision over the implicit function fitting can be obtained by computing a **moving least squares (MLS)**[4]

[2] [Szeliski and Tonnesen 1992]
[3] [Pfister et al. 2000]
[4] [Alexa et al. 2003]

Point-based Representations



(a) (b) (c) (d) (e)

Figure: Point-based surface modeling with moving least squares (MLS) (Pauly, Keiser, Kobbelt et al. 2003) © 2003 ACM

Volumetric Representations

Construct continous inside–outside functions to represent 3D shapes

indicator function (characteristic function) $F(x, y, z)$ to indicate which 3D points are:

- inside $F(x; y; z) < 0$
- outside $F(x; y; z) > 0$

the object.

Superquadrics Formula[5]

$$F(x,y,z) = \left(\left(\frac{x}{a_1}\right)^{2/\epsilon_2} + \left(\frac{y}{a_2}\right)^{2/\epsilon_2} \right)^{\epsilon_2/\epsilon_1} + \left(\frac{x}{a_1}\right)^{2/\epsilon_1} - 1 = 0 \qquad (2)$$

where

- (a_1, a_2) control the extent of model along (x, y)
- (ϵ_1, ϵ_2) control how *square* it is

[5] [Pentland 1986; Solina and Bajcsy 1990; Waithe and Ferrie 1991]

More we know about the object, more detailed and specialized techniques we may use!

- Architecture
- Heads and faces
- Whole body modeling

Model-based Reconstruction

Architecture

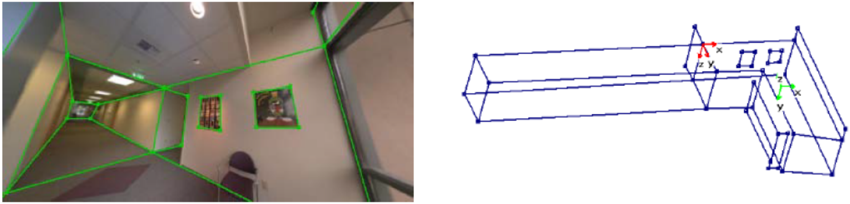
Figure: Interactive architectural modeling using the Façade system[6] © 1996 ACM

[6] [Debevec, Taylor, and Malik 1996]

Model-based Reconstruction

Architecture

Panoramas are used for interior modeling[7]



(a) (b)

Figure: Interactive 3D modeling from panoramas © 1998 IEEE

[7] [Shum, Han, and Szeliski 1998]

Heads and Faces

Figure: Head and expression tracking and re-animation using deformable 3D models.[8] © 2002 Springer

[8] [Pighin, Szeliski, and Salesin 2002]

Model-based Reconstruction

Application: Facial Animation

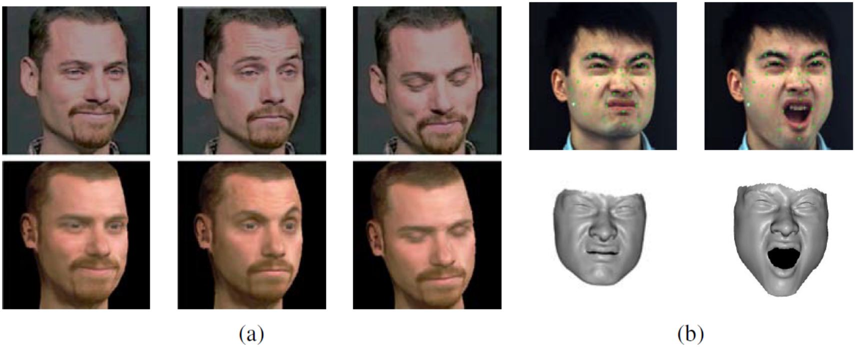


Figure: Head and expression tracking and re-animation using deformable 3D models. © 2002 Springer (a)[9] (b)[10]

[9] [Pighin, Szeliski, and Salesin 2002]
[10] [Zhang, Snavely, Curless et al. 2004]

Recovering Texture Maps and Albedos

map texture coordinates to 3D position:

- $(u, v) \rightarrow (X, Y, Z)$

use more then one image, and then project the maps onto one model

(a) (b) (c)

Figure: Estimating the diffuse albedo and reflectance parameters for a scanned 3D model. [11] © 1997 ACM

[11] [Sato, Wheeler, and Ikeuchi 1997]

Estimating BRDFs

- estimate a general **bidirectional reflectance distribution function (BRDF)** for each point

$$f_r(\theta_i, \phi_i, \theta_r, \phi_r; \lambda); \tag{3}$$

where

- (θ_i, ϕ_i) and (θ_r, ϕ_r) are the angles incident to $\hat{v}_i$ and $\hat{v}_j$

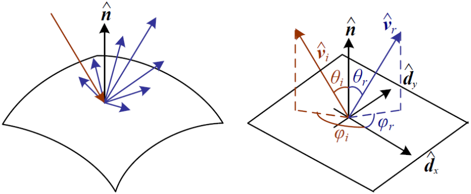


Figure: (a) Light scatters when it hits a surface. (b) The bidirectional reflectance distribution function (BRDF).

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Thank you for listening!