Shape and Visual Appearance Acquisition for Photo-realistic Visualization

Fabio Ganovelli & Massimiliano Corsini

Speaker: Massimiliano Corsini
Visual Computing Lab, ISTI - CNR - Italy
Appearance Acquisition

• 2.1 Introduction
Light-matter interaction. Radiometry in a nutshell. Bidirectional Reflectance Distribution Function (BRDF) and Bidirectional Surface Scattering Reflectance Distribution function (BSSRDF).

• 2.2 BRDF measurement

• 2.3 Reflectance as N-dimensional function estimation

• 2.4 Texture registration
Multi-modal matching through feature-based (keypoints, lines) and statistical methods (mutual information). Statically-fixed shading problems. Color mapping strategies. Intrinsic images (brief notes).
Reflectance as N-dimensional function estimation
Taxonomy of reflectance functions

General scattering function: 14 D
\((x_i, y_i, z_i, \theta_i, \phi_i, \lambda_i, t_i, x_0, y_0, z_0, \theta_0, \phi_0, \lambda_0, t_0)\)

- Ignore time, wavelength dependence
- Assume free space

BSSRDF / 8D-RF: 8D
\((x_i, y_i, \theta_i, \phi_i, x_0, y_0, \theta_0, \phi_0)\)

- Ignore subsurface scattering

SVBRDF / BTF / 6D-RF: 6D
\((x, y, \theta_i, \phi_i, \theta_0, \phi_0)\)

- Ignore spatial variation

BRDF: 4D
\((\theta_i, \phi_i, \theta_0, \phi_0)\)

- Assume isotropy

Isotropic BRDF: 3D
\((\theta_i, \theta_0, |\phi_i - \phi_0|)\)
About the Taxonomy

• The general scattering functions derives from the *plenoptic function*.

• *Spatially Varying BRDF* (SVBRDF) is simply a BRDF which varies along the surface (*SVBRDF = BRDF(u,v)*).
Plenoptic Function

- The *plenoptic function* $P$ is a function which permits to generate every image of a particular space-time chunk of a real scene. This concept was originally proposed by Adelson et al. [Adelson1991].
- It is the flow of light at all position from all directions, at a certain instant of time, i.e. a 7D function:

$$P(x, y, z, \theta, \phi, \lambda, t)$$

Plenoptic function

• Considering *static scene* and *ignore wavelength dependence* we obtain the 5D version of the plenoptic function:

\[ P(x, y, z, \theta, \phi) \]
Light Field

• The term *light field* was coined by A. Gershun [Gershun36] in his classic paper describing the radiometric properties of light in a space.

• If we assume the air to be transparent, the radiance along a ray through the empty space remains constant \( \rightarrow \) we can focus on the light leaving a bounding volume of a 3D object.

Light Field

• The plenoptic function restricted to a bounding volume becomes a 4D function
  \[ P(u,v,\theta,\phi) \]
• If the bounding volume coincides with the object surface, \( P \) corresponds to the BSSRDF with a fixed incident lighting.
Lumigraph

- The Lumigraph [Gortler1996] is a subset of the plenoptic function, i.e. a light field.
- The bounding volume used is a cube.

This allows for easy parameterization, i.e. the two parallel plane parameterization:

\[ L(s, t, u, v) \]
Lumigraph

• As usual, to obtain $L(s,t,u,v)$ we have to find the coefficients of a basis by integrating box functions defined on the parameterization:

$$L(s,t,u,v) = \sum_{i} \sum_{j} \sum_{p} \sum_{q} x_{i,j,p,q} B_{i,j,p,q}(s,t,u,v)$$
Lumigraph

- Considering a 2D Lumigraph \((s,u)\)
Lumigraph – Support basis functions

Depth corrected support
Lumigraph – depth corrected support

Depth-corrected Support in ray space

Non-corrected support in ray space
Image Acquisition

• In order to calculate the inner product, the images have to be *calibrated*
Refletance Field of an Human Face

• We will see now how to capture the reflectance field of an human face [Debevec2000] (!)

• The idea is to capture the radiant light field (4D) for different fixed illumination conditions (directional light).

Reflectance Field of an Human Face

- Capturing the radiant light field for every possible incident light field give us the reflectance function $R$:

\[
R_i = R_i (u_i, v_i, \theta_i, \phi_i) \\
R_r = R_r (u_r, v_r, \theta_r, \phi_r) \\
R(R_i, R_r) = R(u_i, v_i, \theta_i, \phi_i, u_r, v_r, \theta_r, \phi_r)
\]
Non-local Reflectance Field (6D)

- The different incident illumination condition are assumed different directional lights.
- What is it acquired is a non local reflectance field.

\[ R(R_i, R_r) = R(\theta_i, \phi_i, u_r, v_r, \theta_r, \phi_r) \]
Acquisition Device

- The light stage used to acquire the reflectance field is shown in figure.
- The light moves as a spiral (2048 directions are sampled)
- Multiple views are acquired simultaneously
$R_{xy} (\theta, \phi)$

64 x 32 directions
Generate a New Image

• The new image under a combination of the original light sources is:

\[ L(x, y) = \sum_{\theta, \phi} R_{xy}(\theta, \phi) L_i(\theta, \phi) \]
Reflectance Field of an Human Face

- **Light map** × \( \delta A \) = **Normalized light map**
- **Normalized light map** × **Reflectance function** = **Lighting product**
- **Lighting product** |\( \delta \) = **Rendered pixel**
Examples – illumination basis
Changing the lighting environment

Examples
Reflectance Field (6D)

• We will see now another way to acquire a 6D reflectance field [Masselus2003]
• The idea is to use a spherical surface to parameterize the incident light field.

6D Reflectance Field

Vincent Masselus, Pieter Peers, Philip Dutré, and Yves D. Willems
6D Reflectance Field

$$ILF \ L \rightarrow \ L(\theta_p, \phi_p, \theta_a, \phi_a) = L(\Theta_I)$$

Reflectance Field (8D)

$$REFLECTANCE \ FIELD \ R \rightarrow \ R(\Theta_I, \Theta_E)$$
6D Reflectance Field

Exitant light field is restricted to the image plane $L_E(x,y)$ (fixed camera view) $\rightarrow$ 6D Reflectance Field
Light basis to estimate the 6D Reflectance Field
Results

Original Image

Relighted Images
Bidirectional Texture Function (BTF)

• A surface patch of material (a small image, a *texture*) is acquired using approaches similar to the ones for BRDF.

• From each view, a set of photographs in different lighting conditions is acquired → many compression scheme have been proposed.

• *It is not a SVBRDF (!) →* it includes *self-shadowing* and *inter-reflections* effects due to the microstructure of the material.

• Useful to account for the *fine scale* of a material.
BTF example

Cylinder + Texture  Cylinder + BTF

From:
BTF database

From:
Made BRDF Acquisition More Practical

• One of the main challenge of current research in the field
• One of the most effective idea is the *pocket reflectometry* of Ren et al. [Ren2011]

Pocket Reflectometry

• Mimic the *color calibration of a camera*
  – Known color target (Gretag Macbeth)
  – The color target is in the photograph
  – The color are remapped according to the known color
Pocket Reflectometry

(a) Pocket Reflectometry setup

(b) Diagram of the setup with moving light, video camera, and material sample.

(c) Photograph of the setup with a mobile phone capturing images.

Moving Tube

BRDF Chart

Material Sample

Video Camera

Mobile Phone with Video Camera
Pocket Reflectometry

Let’s see some results..
Polynomial Texture Maps (PTM)

- Image-based Lighting technique for the acquisition of appearance (Malzbender et al. – HP laboratories)
- Relightable images are the final product
- Motivations:
  - Three-dimensional illusion is high
  - Viewer’s understanding is improved
  - Rendering is not complex
  - Acquisition setup is cheap
PTM in Cultural Heritage

- Inspection of cuneiform epigraphy (Malzbender et al. 2000)
- In Paleontology, to provide noticeable improvement in imaging of low color contrast, high relief fossils (Hammer et al. 2002)
- To reveal fine details of concoidal knapping fractures on ancient stone tools (Mudge 2004 et al.)
- To provide additional information about the surface of oil paintings (Padfield et al. 2005)
- To build a “virtual exhibition” of the large numismatic collections of the Hospice of Grand St. Bernard (Mudge et al. 2005)
Polynomial Texture Maps

- A set of images in controlled light conditions is acquired but *the camera is fixed*
- The idea is to evaluate per-pixel a function that given the light directions returns the color of the image
Acquisition device

- Devices designed for small objects
  - Illumination dome composed by multiple lights on known positions
  - Illumination dome is hardware controlled
- Reduce to an arc section to make less cumbersome
PTM of large objects

- Digital camera
- Plumb line
- Halogen floodlight (1000W)
- Angle directions scheme
- Tripod
Polynomial Texture Map

• Distant light is assumed (directional light)
• Bi-quadratic polynomial is used to model the per-pixel reflectance functions \( L(.) \)

\[
\begin{align*}
L(l_u, l_v, x, y) &= a_0(x, y) + a_1(x, y)l_u + a_2(x, y)l_v + \\
&+ a_3(x, y)l_u l_v + a_4(x, y)l_u^2 + a_5(x, y)l_v^2
\end{align*}
\]

\[
\begin{align*}
R_f(l_u, l_v, x, y) &= L(l_u, l_v, x, y)R(x, y) \\
G_f(l_u, l_v, x, y) &= L(l_u, l_v, x, y)G(x, y) \\
B_f(l_u, l_v, x, y) &= L(l_u, l_v, x, y)B(x, y)
\end{align*}
\]

LRGB PTM
From PTM to RTI

- Recently, a generalization of PTMs called Reflectance Transformation Images (RTI) has been proposed.
- Some of the results in this direction has been presented at VAST 2009 conference.
  - Prabath Gunawardane et al. “Optimized Image Sampling for View and Light Interpolation”
From PTM to RTI

• A first step has been to replace the bi-quadratic polynomials with other, more complex, functions
  – Spherical or hemi-spherical harmonics (HSH)
  – Adaptive polynomials of high degree
• Another goal has been to remove the fixed viewpoint limitations (i.e. multi-view RTI)
PTM - Demo

- Let’s see a live demo (!)
Normal Unsharp Masking (NUM)
Thanks for the attention.

Question ?