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Transfer of measured transmission distribution data into Radiance

Development and validation of models in Radiance, potential and limitations in daylighting applications

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9th Radiance Workshop, Freiburg 2010

22nd September 2010

National Research Foundation EDB Singapore

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Overview

The bidirectional transmission distribution

Sample and measurement

Model fitting

- Fitting to built-in material models
- Fitting to custom models using function files

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The BRTDF and its measurement

- recall:
  scattering on a sample is described by its Bidirectional Reflection / Transmission Distribution Function (BRTDF)
- measured at a finite resolution
- leads to discrete data for a full sphere

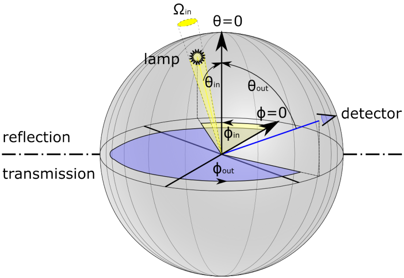

Figure: Coordinate system used in BRTD measurement.

Image courtesy of SERIS

The bidirectional transmission distribution

- for many applications, we are only interested in the transmission
- if we isolate the transmission hemisphere from the complete data set, we get the bidirectional transmission distribution BTD
- the mathematical description of this distribution is the Bidirectional Transmission Distribution Function BTDF (often referred to by BTF)
- transmission scattering happens on the surfaces and in the volume of the sample, but as long as the sample is relatively large and flat, we can treat it as a surface

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Sample and measurement

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Introducing the transmissive sample

- sandblasted glass (you can buy it from Edmund Optics)
- isotropic - transmission depends on theta, not on phi
- uniform - no local variations over the surface are expected
- we ignore color in our example
- this is a simple sample - measuring the BTD of a typical fenestration system is more complex

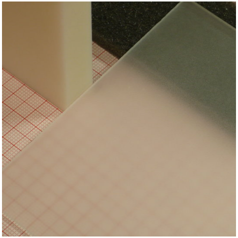

Figure: Photograph showing the sample.

Image courtesy of SERIS

Sample measurement configuration

- measurement on a scanning goniophotometer (PAB pgII)
- halogen lamp with collaminating optic is used as a source
- the detector has a Si response curve with its maximum in the near IR, a hot-mirror is used to block wavelengths beyond 700nm
- first measurement is without sample to measure the flux of the beam
- following measurements with sample are relative to the unobstructed beam distribution

Sample and measurement

Figure: pgII scanning goniophotometer measurement setup at SERIS.

Image courtesy of SERIS

Modeling approaches

Depending on the application, various approaches to use measured BTD data in simulations can be considered

- interpolation on high resolution measurement data, typically needs efficient compression algorithms
- interpolation on low resolution data, resampling of measurement data at regular angular grid (e.g. Klemps)
- use of material models with parameters found by fitting to measurement data

We focus on fitting of models, which is supported by the *func material types in Radiance.

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Pre-processing the measurement data

- the result is a huge set of data triples for each incident direction: theta out, phi out, signal from irradiance-detector
- first, we calculate the radiant flux of the beam as the integral of the unobstructed beam measurement
- than, for each incident direction (so for each of the data files), we need to calculate BTD data for all outgoing directions:
  - divide signal by cos(theta out)
  - divide result by the radiant flux of the reference beam

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Resampling of the measurement data

- measurement data is a scattered data set: the detector signal is not read at given positions, but signal and location are recorded at given intervals
- resulting data is of very high angular resolution
- to ease handling of the datasets, we resample at a regular angular grid and at lower resolution
- grid resolution does not need to be adaptive as sample shows no distinct peak - with other samples this would not work!

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Fitting material models to measurement data

- We use an objective function similar to Ngan et al. weighted by $\cos(\theta_i)$:

  $g_{BRTDF}(\theta_i, \phi_i, \theta_o, \phi_o) =$

  $(BRTDdata(\theta_i, \phi_i, \theta_o, \phi_o) - BRTDF(\theta_i, \phi_i, \theta_o, \phi_o)) \cdot \cos(\theta_i)$

- The fitting routine minimized this function by finding parameters for the function *BRTDF* so that

  $\sum_{k=1}^{N} g_{BRTDF}\left(\theta_i^{(k)}, \phi_i^{(k)}, \theta_o^{(k)}, \phi_o^{(k)}\right)^2 \rightarrow \min$

- We use the routine sqp() of the freely available Octave environment for the parameter estimation.

Radiance's built-in models

- Radiance offers several built-in models to describe transmissive materials: dielectric, interface, trans, glass
- built-in models are consistently supported in the code and well-documented
- fitting to built-in models leads to parameters that can be used in scene descriptions in the well-known scene description language

Model fitting

The trans material in Radiance 4.0

Radiance 4.0 uses the Ward BRTDF for the trans material:

specular transmission:

$$t_{R4.0}(\theta_i,\phi_i,\theta_o,\phi_o) = \frac{\exp((2(\vec{i},\vec{t})-2)/\alpha^2)}{\pi\alpha^2 \cos\theta_i(-\cos\theta_o)}$$

the BTDF then becomes:

$$BTDF_{R4.0}(\theta_i,\phi_i,\theta_o,\phi_o) =$$

$$\rho\cdot\left(\frac{trans\cdot(1-r_s)\cdot(1-t_s)}{\pi} + (trans\cdot(1-r_s)\cdot t_s)\cdot t_{R4.0}(\theta_i,\phi_i,\theta_o,\phi_o)\right)$$

where ρ is the fraction of light that is not absorbed, r_s the fraction of reflected light that is not scattered, *trans* the fraction of light that is transmitted, t_s the fraction of transmitted light that is not scattered

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Model fitting

Radiance 4.0 trans material definition

- the fitting function for the model was implemented in Octave
- absorption was found to be very low, the arguments A1-A3 for trans were set to 1.0
- arguments A4-A7 are found by the fit: r_s, *roughness*, *trans*, t_s
- fitting error 0.038637 per data point

definition of the material using trans in Radiance 4.0:

```
void trans builtin4.0
0
0
7     1.0                  1.0                  1.0
      0.032053765492758    0.196764986217294
      0.842221933204623    0.492961744801061
```

Model fitting

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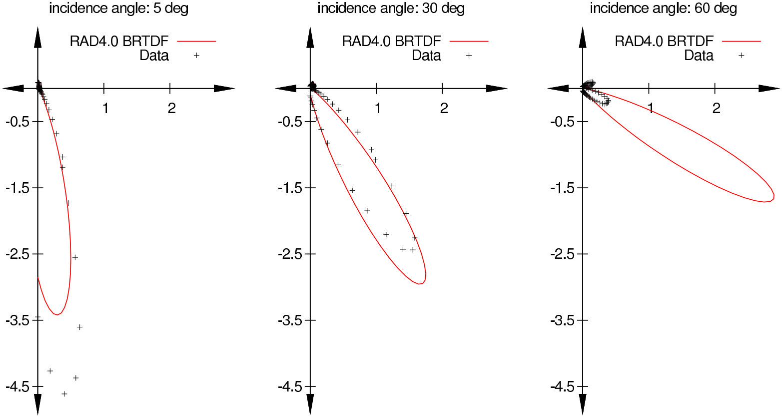
Fitting results for Radiance 4.0



The trans material in Radiance HEAD

- the fitting error reveals an error in the trans material's implementation in Radiance 4.0 introduced with version 3.6
- the original, correct material is used again in HEAD after 7th May 2010

Radiance HEAD uses the original model for specular transmission:

specular transmission:

$$t_{Rorig}(\theta_i, \phi_i, \theta_o, \phi_o) = \frac{\exp((2(\vec{i},\vec{t}) - 2)/\alpha^2)}{\pi\alpha^2\sqrt{\cos\theta_i(-\cos\theta_o)}}$$

Model fitting

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Radiance HEAD trans material definition

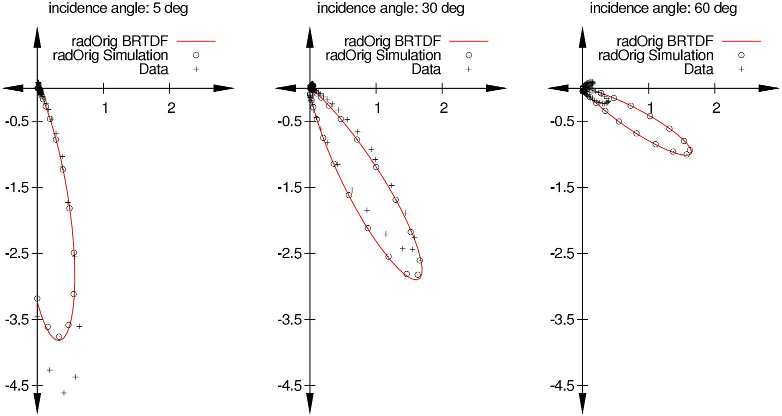
- again A1-A3 set to 1.0, A4-A7 found using Octave
- fitting error 0.014617 per data point

definition of the material using trans in Radiance HEAD:

```
void trans builtinHead
0
0
7       1.0                   1.0                  1.0
        0.0348859364789284    0.207070895419172
        0.838543229278675     0.624752536452917
```

Model fitting

Fitting results for Radiance HEAD



Custom material models in Radiance

- Radiance offers interfaces to describe custom material models using its functional language (“cal-files”) and accessing external data files
- using such custom models may lead to a closer fit to measured data

support for these materials is, unfortunately, limited

- photon map: no support for custom BRTDF models
- classic Radiance: indirect diffuse (“ambient”) calculation uses the standard built-in model, only direct and specular indirect calculation based on functional description
- a work-around may be the use of illum to include the outgoing distribution as light sources into the ambient calculation (see Greg’s latest genBSDF tool)

The Phong Shading model

Adoption of the Phong reflection model to transmission:

specular transmission:

$$t_{Phong}(\theta_i, \phi_i, \theta_o, \phi_o) = \frac{\alpha+2}{2\pi}\cos(\gamma)^\alpha = \frac{\alpha+2}{2\pi}(\vec{i}, \vec{t})^\alpha$$

where γ is the angle between the light source direction $\vec{i}$ and the perfectly transmitted direction $\vec{t}$. The BTDF becomes:

$$BTDF_{Phong}(\theta_i, \phi_i, \theta_o, \phi_o) =$$

$$\rho \cdot \left(\frac{trans \cdot (1 - r_s) \cdot (1 - t_s)}{\pi} + (trans \cdot (1 - r_s) \cdot t_s) \cdot t_{Phong}(\theta_i, \phi_i, \theta_o, \phi_o) \right)$$

where ρ again is the fraction of light that is not absorbed, r_s the fraction of reflected light that is not scattered, *trans* the fraction of light that is transmitted, t_s the fraction of transmitted light that is not scattered as needed for the transfunc definition.

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Model fitting

Phong transfunc material definition

- in a first cycle, the phong parameter α found as 45.26 led to fitting errors and was then fixed as $\alpha = 45$
- A1-A3 set to 1, A4-A6 by fitting: r_s, *trans*, t_s, A7 is α
- fitting error 0.0091188 per data point

definition of the material using trans in Radiance:

```
void transfunc phong
  2    brtd phong.cal
  0
  7    1.0                     1.0                  1.0
       0.00818591934039958     0.820354776335826
       0.649301146651907       45
```

Model fitting

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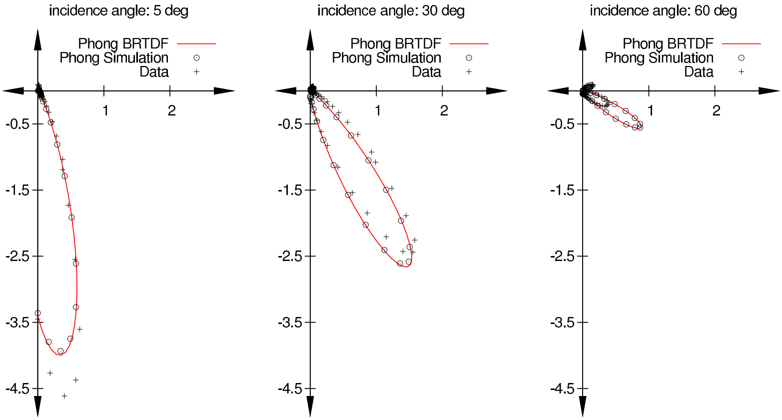
Titting results for Phong Shading



An improved BTDF model for our sample

Based on improved Ward-BRTDF model by Geisler-Moroder & Dür:

specular transmission:

$$t_{New}(\theta_i, \phi_i, \theta_o, \phi_o) = \frac{\exp((2(\vec{i}, \vec{t}) - 2) \cdot \cos(\theta_i)^2 / \alpha^2) \cdot \cos(\theta_i)^2}{\pi \alpha^2 \sqrt{\cos \theta_i (-\cos \theta_o)}}$$

The BTDF becomes:

$$BTDF_{New}(\theta_i, \phi_i, \theta_o, \phi_o) =$$

$$\rho \cdot \left(\frac{trans \cdot (1 - r_s) \cdot (1 - t_s)}{\pi} + (trans \cdot (1 - r_s) \cdot t_s) \cdot t_{New}(\theta_i, \phi_i, \theta_o, \phi_o) \right)$$

where ρ again is the fraction of light that is not absorbed, r_s the fraction of reflected light that is not scattered, *trans* the fraction of light that is transmitted, t_s the fraction of transmitted light that is not scattered as needed for the transfunc definition.

Improved BTDF transfunc material definition

- A1-A3 set to 1, A4-A7 by fitting: r_s, roughness parameter α, *trans*, t_s
- fitting error 0.0064912 per data point

definition of the material using transfunc in Radiance:

```
void transfunc new
  2      brtd new.cal
  0
  7      1.0                    1.0                  1.0
         0.0287632015638308     0.201073097358677
         0.820341265456635      0.656166764548217
```

Model fitting

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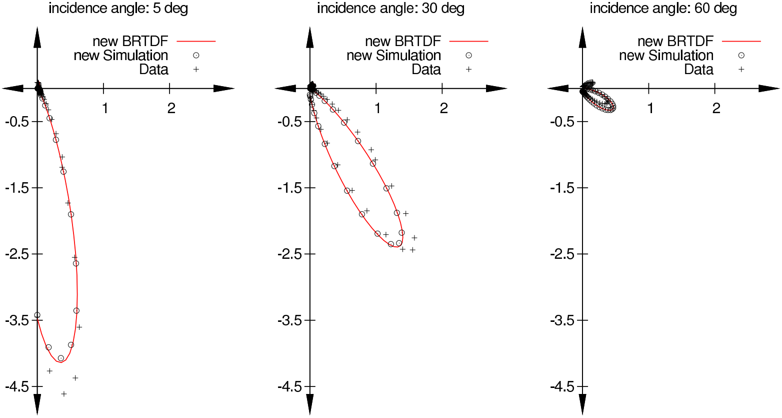
Fitting results for an improved BTDF model



Functional description of the BTDF model

As an example, the functional description of the optimized BTDF in newTrans_brtd.cal:

```
(...)

{ BTDF } Ldot(x,y,z) = x*Nx + y*Ny + z*Nz; trans(x,y,z) =
exp((2.0*dot_t_l(x,y,z)-2.0)*Ldot(x,y,z)^2/alpha2)*
Ldot(x,y,z)^2/(PI*alpha2*sqrt(-Ldot(x,y,z)*Rdot));

{ BRTDF } brtd(x,y,z) = if(Ldot(x,y,z),refl(x,y,z),trans(x,y,z));
```

Thank you for your attention!

More information:

www.seris.sg