Virtual Heliodon:
Spatially Augmented Reality for Architectural Daylighting Design

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Natural Light vs. Electric Light

*Lighting accounts for 22% of US electricity consumption*
Lights on, blinds closed
• 620 lux
• 620 lux

Lights off, blinds closed
• 110 lux
• 180 lux

Lights off, blinds open
• 320 lux
• 880 lux

Lights off, no blinds
• 380 lux
• 1030 lux

500-1000 lux recommended for reading
direct sunlight ≈ 100,000 lux
Architectural Daylighting Design: The use of windows and reflective surfaces to allow natural light from the sun and sky to provide effective and interesting internal illumination.

Residential design proposal by Mark Cabrinha
Analysis with Traditional Heliodon

Shadows and light penetration can be observed on small scale physical model
Related Work:

- **Daylighting Design**
  - Radiance, Greg Ward Larson

- **Virtual / Augmented Reality**
  - CAVE (Cruz-Neira et al., 1992)
  - Interior Architectural design (Mackie et al., 2004, Dunston et. al, 2007)

- **Spatially Augmented Reality**
  - Office of the future (Raskar et al., 1998)
  - Everywhere Display (Underkoffler et al., 1999)
  - Shader Lamps (Raskar et al., 2001)
  - Automatically-calibrated cameras and projectors (Raskar et al., 2001)
  - Multi-planar display (Ashdown et al., 2004)
  - Shadows and occlusions (Audet & Cooperstock, 2007)
Table-top Daylighting Design

camera to detect geometry

4 projectors to display solution

design sketched with foam-core walls
Algorithms and Implementation

• Hybrid Rendering Algorithm
• Model Construction
• Camera & Projector Calibration
• Primitive Detection
• Multi-Projector Display
Algorithms and Implementation

• Hybrid Rendering Algorithm
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Radiosity

- Global illumination algorithm
  - Diffuse surfaces
- Why not radiosity alone?
  - Low resolution mesh → inaccurate shadows
- Why do we need “hard shadows”?
  - More realistic
  - More intuition about scene geometry & lighting
Interactive Global Illumination: Hybrid Radiosity/Shadow Volumes

1. Radiosity
2. First bounce
3. Indirect = 1-2
4. Shadow volumes
5. Final = 3+4

Exploit smoothness in indirect illumination
Efficiently compute direct illumination
Algorithms and Implementation

- Hybrid Rendering Algorithm
- Model Construction
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- Primitive Detection
- Multi-Projector Display
Sketch Interpretation

*red:* exterior wall w/ window
*green:* exterior wall
*yellow:* interior wall
*blue* north arrow

software automatically constructs closed polygonal model for simulation
Algorithms and Implementation

- Hybrid Rendering Algorithm
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Camera Calibration

• Using Zhang’s algorithm [Zhang 1999] to estimate the intrinsic parameters of camera
  – Calibration target consisting of 212 black and white corner marks on a white background
  – 40 pictures taken at different orientations
Projector Calibration

• Tsai’s algorithm
  [Tsai 1987]
  – Uniformly spaced horizontal planes

*Projector calibration*

*Common coordinate system*
Algorithms and Implementation

- Hybrid Rendering Algorithm
- Model Construction
- Camera & Projector Calibration
- Primitive Detection
- Multi-Projector Display
Primitive Detection

- Color classification
- RANSAC: fit line to edges
- $2D \rightarrow 3D$, projection matrix
Watertight Mesh for Simulation

Detected geometry

Projection surfaces

“Fill-in” geometry

“Extra” physical geometry

(model interior)
Algorithms and Implementation

- Hybrid Rendering Algorithm
- Model Construction
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- Primitive Detection
- Multi-Projector Display
Multi-Projector Display

- Radiance adjustment
- Intensity blending
  - Smooths transitions between projectors
  - Each vertex in the mesh has a “best projector” for display

\[ I = E \frac{r^2}{\rho \cos \theta} \]
Results

• For a geometry with 1500 triangles
  – 0.6 seconds to relight for changing time / day, north orientation, etc.
  – 6-7 seconds to generate the projection images for a new geometry
    • Image processing: 0.05 seconds
    • Remeshing: 2.5 seconds
    • Form factor computation: 3 seconds
<table>
<thead>
<tr>
<th>Traditional Heliodon</th>
<th>Virtual Heliodon</th>
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<tr>
<td>• Must peer in the windows, but avoid blocking the “sun”</td>
<td>• Ceiling has been removed allowing easy viewing</td>
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<td>• Close approximations of all materials must be used in model construction</td>
<td>• Less precision is needed in joining walls</td>
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<td>• Model construction is tedious</td>
<td>• Materials are specified digitally and do not require a physical sample of the material</td>
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<td>• Initial construction and edits are fast and easy</td>
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Ongoing and Future Work

• Formal user studies
• Robust image processing, e.g., ignore users’ hands
• Table surfaces, curved walls, sloped ceilings
• Consider dynamic range of projectors
• Complex fenestration (window) materials
• Compensate for secondary scattering of projected imagery
Light-Redirecting Materials

Prismatic panels available in late 1800’s, but lost popularity when electric lighting was introduced.
Secondary Scattering Compensation

*Desired illumination*

*Naïve projection*

*Compensated*

*Compensated projection*
Thanks!

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