"Light: from simple optics to amazing applications"

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Graduate Students and Undergraduate researchers
Outline

• Geometrical optics reminders: reflection, refraction, Snell’s Law, Total Internal Reflection (TIR)
• Applications of TIR: fiber optics, retro-reflectors, guiding film
• Frustrated TIR – applications to “real” black and white reflective display. Electronic paper?
• New Developments in Solar Lighting Systems based on Prism Light Guides will be presented by Alex Rosemann
• New concept of electronic display – High Dynamic Range Display from our Spin-off company Brightside Technologies - will be presented by Helge Seetzen
• Ray model of light.
• When we can use it?
• Wavelength of light 0.4 - 0.6\(\mu\)m
Snell’s Law:
When light passes from the medium with refraction index $n_1$ into another with refraction index $n_2$:

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$
Slide by Lorne Whitehead
Snell’s Law

\[ \theta_r = \theta_i \quad \theta_t = \sin^{-1}\left(\frac{n_1}{n_2}\sin(\theta_i)\right) \]

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Slide by Lorne Whitehead
\[ \theta_r = \theta_i \quad \theta_t = \text{no answer!} \]

Total Internal Reflection!
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**Total Internal Reflection!**

Slide by Lorne Whitehead
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**Total Internal Reflection!**

Slide by Lorne Whitehead
Critical angle

- \( n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \)
- \( \theta_2 = 90^\circ \)
- \( \theta_1 = \sin^{-1}(n_2 / n_1) \)
- For water \( \theta_1 = 49^\circ \)
- For glass \( \theta_1 = 42^\circ \)
Fiber Optics

- Fiber optics for communication
Fiber Optics
Endoscopes

(a)
Guiding film
3M Optical Lighting Film (OLF)

Micro-replicated light guiding film uses linear 90 degree prisms
Samples
Rainbow
Reflective side
Transparent side
Image deformations
The critical angle for total internal reflection is

\[ \alpha_c = \sin^{-1}\left(\frac{n_1}{n_2}\right) = 38.7^\circ. \]

The angle of incidence, 45°, is larger than critical, therefore a total internal reflection occurs and the light is reflected at the angle 45°. The same happens on the second face, so the light is send back and leaves the film at 180° to the original direction.
The light comes from the medium with a smaller so there is no total internal reflection. The refracted angle is

\[ \alpha_r = \sin^{-1}(\sin(45^\circ) n_1/n_2) = 26.2^\circ. \]

The incidence angle on the bottom surface is

45 - 26.2 = 18.8

which is less than critical angle so there in no total internal reflection and we have an other refraction:

\[ \alpha_{r_2} = \sin^{-1}(\sin(18.8^\circ) n_2/n_1) = 31^\circ. \]
Retro-Reflection

Light undergoing 1-3 reflections from a corner cube with the inner reflecting surfaces returns at 180 degree to the incident light - “retro-reflection”.

3M Diamond Grade™ Reflective Sheeting

An array of corner cubes forms retro-reflective sheet material
The prism light guide
McDonald’s Roof Beam Light Guide System
Vertical Light Guides 3M Bldg. 275 St. Paul, MN
Light Guide Illumination of Boston’s Callahan Tunnel
Highly directional down lighting from new Light Guides and Sulfur Lamps in Smithsonian Air and Space Museum
Solar Lighting Systems based on Prism Light Guides

- Long History
- New Developments will be presented by Alex
Frustrated TIR – applications to “real” black and white reflective display.
Electronic paper?
TIR...
Frustrated TIR
Principle of a TIR-based Reflective Display

- Light ray is reflected
- Gap ($n_2$)
- "White State"

- Light ray is absorbed
- Micro-prisms ($n_1$)
- Absorptive material
- "Black State"
Electrophoresis

• Controlled motion of charged particles in a medium in response to an applied electric field
electrophoretic mobility: $\mu$
Particle velocity: \( v = \frac{\mu V}{d} \)
Slide by Michele Mossman
Slide by Michele Mossman
Electrophoretic TIR Display

ON STATE

OFF STATE

High Index Retro-reflective Surface

Electrophoretic Suspension

Slide by Michele Mossman
The TIR-based reflective display has an image quality very similar to printed white paper.
Hemispherical Microstructures

Slide by Michele Mossman
Hemispherical Microstructures

Slide by Michele Mossman
New concept of electronic display – High Dynamic Range Display from our Spin-off company Brightside Technologies - Helge
Light: from simple optics to amazing applications

The Solar Lighting Project at UBC

Alexander Rosemann

February 18, 2006
Solar Lighting Project – Project Partners

• Korea Institute of Energy Research, Taejon, Korea

• Natural Resources Canada, Ottawa, ON

• University of British Columbia Vancouver, BC
Motivation for daylight utilisation

In Vancouver, daylight is available during 94% of the working hours.
Project Aim

• Daylight Utilisation in Deeper Building zones
• Use of materials that are potentially low-cost in mass production
• Demonstration of the system in a portable test environment
• Demonstration of the system in a real building
• …
Example building cross section with solar canopies on south-facing wall feeding prism light guides
UBC Solar Lighting Project

- Sun
- Adaptive Butterfly Array
- Helio-box
- Solar Canopy
- Control Unit
- Light Guide
- TFL + el. ballasts
- Hybrid Prism Light Guide
- Portable Testroom
Heliostat design

Sun positions in Vancouver
Adaptive Butterfly Array
Adaptive Butterfly Array – April 21st
Prism Light Guide

Fluorescent Lamps
Extractor

Highly reflective film
Microprismatic film
Portable testroom
South Wall
Redirecting the direct sunlight with the Adaptive Butterfly Array
Measurement Overview

- Artificial Lighting
- Daylighting
  - Daylight entering through the South window
  - Daylight entering through the solar canopy system

What did we measure?
Illuminance (Luminous Flux / Area), measured in lx
Measuring height: 0.8 m

What are the target values?
Recommendation in office buildings: 500 lx on the task area and 300 lx in surrounding areas
Artificial lighting
dimming characteristics

Illuminance distribution for a dimming voltage of 10 V. The relative illuminance distribution does not change with dimming.

The mean illuminance varies with the dimming voltage as shown in the figure. This data is useful for the control algorithm.
Daylighting measurements 1

**Setup:**
- SOUTH WALL uncovered
- Hybrid light guide blocked

\[ \bar{E} = 527 \text{ lx} \]

The illuminance is very non-uniform. Although the mean illuminance is above 500 lx, the values drop below 500 lx in the second half of the room. For this scenario artificial lighting is required all the time.
Daylighting measurements 2

Setup: SOUTH WALL covered
Hybrid light guide open
11:08 am TLT

\[ \bar{E} = 550 \text{ lx} \]

The mean illuminance is above 500 lx, the values are well above 500 lx in the centre line, even in the second half of the room. For this scenario artificial lighting is not required.
Combined Daylighting Results

**Setup:**
- SOUTH WALL open
- Hybrid light guide open
- Simulated results

The mean illuminance is above 500 lx, the values are well above 500 lx in the centre line, even in the second half of the room. For this scenario artificial lighting is not required.
Illumination in deeper building zones

South wall open
Thank you for your attention

The Solar lighting project at UBC
Luminous Transmittance of the optical lighting film

Lichttransmissionsgrad einer prismatischen Folie als Funktion des Lichteinfalls
High Dynamic Range Imaging Pipeline

Helge Seetzen

February, 2006
Imaging Pipeline – 8-bit rules!
Image Quality – What are we missing?

Human Overall Luminance Vision Range
(14 orders of magnitude, scale in log cd/m²)

-6  -4  -2  0  2  4  6  8

starlight  moonlight  indoor lighting  sunlight

Human Simultaneous Luminance Vision Range

5 orders of magnitude

Today’s Devices

2-3 orders

BrightSide Technologies

5 orders of magnitude
Overcoming the 8-bit Barrier

Requirements:

1. High Dynamic Range

2. Compatibility
   - New devices need to function in 8-bit environment and still deliver significant benefit
   - New devices need to be usable in stand-alone mode

3. Cost
   - Ideally no extra cost compared to 8-bit devices
   - If extra cost is necessary then in line with benefit
The Scene

Stanford Memorial Church
Courtesy Paul Debevec
Image Capture – Multiple Exposures
Image Capture – 8-bit to 16-bit CCDs

Compatibility
• existing CCD
• can output 8-bit image (ignore second exposure)

Cost
• firmware change only
• zero incremental cost
Data Storage – Size is a Problem!

- RAW Image Data -> 4.5Mb (100%)
- Radiance XYZE -> 1.3Mb (29%)
- 8-bit BMP -> 1.2Mb (27%)
- 8-bit JPEG -> 65kb (1.4%)
- JPEG HDR™ -> 70kb (1.5%)
Data Storage – JPEG / MPEG HDR

HDR Image

Tone Map
Standard or BrightSide

Tone Mapped Image

Encoder
L(HDR(x,y))
L(TM(x,y))

Sub-band
Ratio Image

Standard JPEG or MPEG Compression

Compressed
RGB8 JPEG or MPEG with Sub-band

Sub-band Encoding of HDR Images

RGB8 Tone Mapped Image

Decompress with Sub-band

No

Normal Decompress

Tone Mapped Image

Decompress

Yes

HDR Device?

Sub-band Ratio Image

Decoder
L(TM(x,y))*RI

HDR Image
Data Storage – Image Quality

**Compatibility**
- indistinguishable from RGB8 JPEG
- tone mapped image can be customized
- compatible with most formats

**Cost**
- very low (~5% extra size)
- real time decoding possible
Imaging Pipeline – Our Progress
Image Processing

- Floating point GPUs are becoming standard
- Most CG and Games done in HDR today
- TV remains low dynamic range and is unlikely to change soon
- Reverse Tone Mapping and Saturation Extension provide quality gain even for legacy content
Image Processing - Extension

Gradiant
Colour Space
Size

Pixel Number

16-bit Value
Image Processing - Extension

Compatibility
• only needed for legacy content
• calculation supported in 8-bit processor

Cost
• very fast (1-2 operations per pixel)
Imaging Pipeline – Our Progress
Display Technology – Concept

High resolution colour LCD

High Dynamic Range Display

Low resolution Individually Modulated LED array
Display Technology – Image Processing

HDR Image

LED array

LCD with correction

Output image
Display Technology – Review

- **Compatibility**
  - Legacy support through Reverse Tone Mapping and Saturation Extension
  - Small number of LEDs allows encoding of LED data in conventional video signal

- **Cost**
  - LED cost money (less every day)
  - Significant power reduction (~25% of comparable constant backlight LCD on average)
Display Technology – Results

Stanford Memorial Church
Courtesy Paul Debevec
Imaging Pipeline – Completing the Equation
“When these displays become more affordable in the next year or two, I don't know how we'll ever go back to the old way.”

David Kirk, NVIDIA

“The item with the biggest “WOW” factor at SIGGRAPH”

Game Developers Magazine

“The Future of Gaming”

Hollywood Reporter Magazine

“… creating the unnerving sensation that you are somehow seeing beyond the display screen”

VFXWorld Magazine