Fundamentals of Vision Lighting

February, 2012

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Proper lighting environment?
Consistent lighting environment?
Light show display to impress your supervisor?
What do we mean by “proper” anyway?

What we really require is control of the lighting environment for producing:

- Sample inspection & system appropriate lighting
- To the extent possible, standardization of components, techniques, implementation and operation
- Reproducibility of inspection results
- Robustness to handle variations of “all sorts”
Topics

- Review of Light for Vision Illumination
- Vision Lighting Sources
- Review of Illumination and Techniques
- Sample Applications Examples
- Using Near IR and Near UV Light
- Filters are Useful, Too!
- Standard Lighting Method
Standard Lighting Method

1) Knowledge of:
   - Lighting types and application advantages & disadvantages
   - Vision camera sensor quantum efficiency & spectral range
   - Illumination Techniques and their application fields relative to surface flatness & surface reflectivity
   - Illumination Technique Requirements & Limitations

2) Familiarity with the 4 Cornerstones of Vision Illumination:
   - Geometry
   - Structure (Pattern)
   - Wavelength (Color)
   - Filtering

3) Detailed Analysis of:
   - Immediate Inspection Environment – Physical constraints and requirements
   - Sample – Light Interactions w/ respect to your Unique Sample
Vision Lighting Development

Art?

Science?

Or both?

Image Courtesy NASA - HST

Images Courtesy Wikimedia Commons Public Domain
Wave and Look (most common)
- Image the part while trying different sources at different positions

Scientific Analysis (most effective)
- Analyze the imaging environment and short-list the best solution possibilities

Test Lights! (saves time)
- Test on the bench then the floor to verify your analysis
Review of Light for Vision Illumination
Light: Photons propagating as a transverse electromagnetic energy wave and characterized by:

- Frequency: Varies inversely with wavelength (Hz – waves/sec)
- Measured Photon Intensity: Radiometric and Photometric (more later)
- Wavelength (Most common for Machine Vision)
  - expressed in nanometers (nm) or microns (um)
  - 100 nm = 0.1 um = $1/10,000,000^{th}$ of a meter!
  - a human hair is ~ 100 um (100,000 nm) wide

Photons:

Energy packets exhibiting properties of waves and particles.
Light diffracts (bends) around edges – implications for back lighting.

It moves more slowly, thus refracts (disperses) through media of different densities.

The amount of refraction is directly proportional to its frequency, and thus inversely proportional to its wavelength.

Example - violet light has a higher frequency, thus it is refracted more than red through a given medium.

The amount of refraction also is directly proportional to the ratio of media densities and inversely proportional to the angle of incidence.
Light Refraction

Example

Light is refracted as:

\[ \frac{n \text{ (glass)}}{n \text{ (air)}} = \frac{1.5}{1.0} = 1.5 \]

\( n \) = Index of Refraction

Visible light is a very small portion of the “electromagnetic spectrum”

How small?

\[ \sim \frac{1}{1000^{th}} \text{ of } 1\%! \]
Characterizing Light

THE ELECTROMAGNETIC SPECTRUM

<table>
<thead>
<tr>
<th>Wavelength (meters)</th>
<th>Radio</th>
<th>Microwave</th>
<th>Infrared</th>
<th>Visible</th>
<th>Ultraviolet</th>
<th>X-ray</th>
<th>Gamma Ray</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$10^3$</td>
<td>$10^{-2}$</td>
<td>$10^{-5}$</td>
<td>$.5 \times 10^{-6}$</td>
<td>$10^{-8}$</td>
<td>$10^{-10}$</td>
<td>$10^{-12}$</td>
</tr>
</tbody>
</table>

About the size of...
- Buildings
- Humans
- Honey Bee
- Pinpoint
- Protozoans
- Molecules
- Atoms
- Atomic Nuclei

Long Wavelength
Larger # Photons, but Lower Energy ea
Low Frequency

Short Wavelength
Smaller # Photons, but High Energy ea
High Frequency

Courtesy of NASA Public Domain
Sources

- LED - Light Emitting Diode
- Quartz Halogen – W/ Fiber Optics
- Fluorescent
- Xenon (High-Performance Strobing)
- Metal Halide (Microscopy)
- High Pressure Sodium
Primary Light Sources

- Life Expectancy
- Application Flexibility
- Output Stability
- Cost Effectiveness / Hr
- Strobing
- Output Intensity
- Large Area / Long WD

Legend:
- LED
- Quartz Halogen
- Fluorescent

- 0
- 1
- 2
- 3
- 4
- 5

- 1 / Heat Output
- Output Intensity
- Large Area / Long WD
- Strobing
- Life Expectancy
- Application Flexibility
- Output Stability
- Cost Effectiveness / Hr

- LED
- Quartz Halogen
- Fluorescent
<table>
<thead>
<tr>
<th>Type</th>
<th>Spectrum</th>
<th>Intensity</th>
<th>Life (hrs)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td>Various</td>
<td>Bright to Very Bright</td>
<td>Up to 100,000</td>
<td>Long life&lt;br&gt;Stable Output&lt;br&gt;Small Area **</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>White w/blue-green, yellow</td>
<td>Bright</td>
<td>5000 to 7000</td>
<td>Inexpensive&lt;br&gt;Need High Freq&lt;br&gt;Low Heat</td>
</tr>
<tr>
<td>Halogen</td>
<td>White w/yellow</td>
<td>Very Bright</td>
<td>200 to 3000</td>
<td>Inexpensive&lt;br&gt;High Heat</td>
</tr>
<tr>
<td>Xenon</td>
<td>White w/blue</td>
<td>Very Bright</td>
<td>3000 to 7000</td>
<td>Expensive&lt;br&gt;Stable</td>
</tr>
<tr>
<td>Electro-Luminescent</td>
<td>Green</td>
<td>Dim</td>
<td>2000 to 5000</td>
<td>Very Thin&lt;br&gt;Low Heat</td>
</tr>
</tbody>
</table>
Brief Review of Light and Optics for Vision Illumination
Sample-Appropriate Lighting

The lighting type and technique, tailored for the specific application, that allows the vision system do its job accurately and reproducibly.

It’s All About (creating) Contrast!

1) Maximum contrast
   • features of interest

2) Minimum contrast
   • features of no interest (noise)

3) Minimum sensitivity to normal variations
   • minor part differences
   • presence of, or change in ambient lighting
   • sample handling / presentation differences
The Visible Light Spectrum

- Light is Seen Differently by film, humans, and CCDs.
Let your vision system determine sensitivity and wavelength!
Sample / Light Interaction

Total Light In =
Reflected + Absorbed + Transmitted + Emitted Light

Light reflects at the angle of incidence
\[ \phi_1 = \phi_2 \]
Solid angle: Effective surface area of a light / radius$^2$ of the cone.

- Ring Light or Spot Light
  - Small Solid Angle

- Ring Light or Spot Light at greater WD
  - Smaller Solid Angle

- Dome, Axial Diffuse or Flat Diffuse
  - Large Solid Angle

Note: Shorter WD and larger light increase the effective solid angle.
Light Interaction

Convergence of Concepts
(Sample – Light – Lens**)

Contrast
Resolution
  Spatial
  Spectral
Focal Length / Field of View
Focus
Working Distance / Stand-off
Sensitivity

**3-D Working Volume: Strong inter-relationship

You cannot solve vision problems working in a vacuum!
Review of Lighting Techniques
4 Lighting Cornerstones

How do we change contrast?

- Change Light / Sample / Camera **Geometry**
  - 3-D spatial relationship
- Change Light Pattern (**Structure**)
  - Light Head Type: Spot, Line, Dome, Array
  - Illumination Type: B.F. – D.F. – Diffuse – B.L.
- Change Spectrum (**Color / Wavelength**)
  - Monochrome / White vs. Sample and Camera Response
  - Warm vs. Cool color families – Object vs. Background
- Change Light Character (**Filtering**)
  - Affecting the wavelength / direction of light to the camera

Need to understand the impact of incident light on both the part of interest and its immediate background!
Common Lighting Techniques

- Partial Bright Field
- Dark Field
- Back Lighting
- Diffuse Dome
- Axial Diffuse
- Flat Diffuse
- Full Bright Field
Bright Field vs. Dark Field

Typical Co-axial Ring Light – Sample Geometry

Bright Field

Dark Field
Dark Field vs. Bright Field

Partial Bright Field
Lights in White Area

Dark Field Lights in
Grey Areas

Mirrored Surface

Scratch
Bright Field vs. Dark Field Lighting

Bright Field Lighting

Dark Field Lighting
Dark Field Example

- Angled light – 45 degrees or less
- Used on highly reflective surfaces
- OCR or surface defect applications
Stamped Date Code

- Recessed metal part
- Reflective, textured, flat or curved surface

12-08-02

Bright field spot light
UPC Bar Code

Reading under Cellophane

Axial Diffuse Illuminator
Diffuse Dome

- Similar to the light on an overcast day.
- Creates minimal glare.
- Purple Ink
- Concave, reflective surface

Bright Field Ring Light
- Surface Texture Is Deemphasized
- Best Choice for Curved Shiny Parts
Axial Diffuse

- Light directed at beam splitter
- Used on reflective objects
Axial Diffuse Illumination

- Surface Texture Is Emphasized
- Angled Elevation Changes Are Darkened
Flat Diffuse

- Diffuse sheet directed downward
- Long WD and larger FOV
- Hybrid diffuse (dome and coaxial)
Backlight Illumination

- Locates edges – Gauging
- Internal defects in translucent parts
- Hole-finding
- Presence / Absence
- Vision-Guided Robotics: Incl. Pick & Place
- Useful for translucent materials
Light Diffraction:
Bending around obstacles

\[ \Theta = \frac{\lambda}{D} \], where \( \Theta \) is the diffraction angle and \( D \) is opening width

High-accuracy gauging:
Use monochrome light
Shorter wavelengths best
Use collimation – parallel rays
Longer \( \lambda \) light penetrates samples better
Simple Back Lighting Example

- Small Bottle – blue-green
- Consider colors and materials properties also.
- Longer wavelength isn’t always best for penetration!

660 nm Red Backlight

880 nm IR Backlight

470 nm Blue Backlight
Collimated Backlight Illumination

No Collimation

Collimation Film
High- Accuracy Gauging

- Back lighting
- Monochrome light better
  - Shorter wavelength a little better
- Collimation even better
  - Optical collimation better than film
- Minimal distortion lens
  - Telecentric lens best
- Measurement calibration – CRITICAL*
- Focus - CRITICAL*

* Less critical if using a telecentric lens
Technique vs. Sample Surface

Surface Reflectivity

Matte  Mixed  Mirror Specular

Flat  Uneven

Geometry

Independent Area

Surface Texture / Shape

Bright Field  Dark Field

Flat Diffuse  Axial Diffuse

Diffuse Dome / Cylinder

Curved
Inspection Environment

Physical Constraints
- Access for camera, lens & lighting in 3-D (working volume)
- The size and shape of the working volume
- Min and max camera, lighting working distance and FOV

Part Characteristics
- Sample stationary, moving, or indexed?
- If moving or indexed, speeds, feeds & expected cycle time?
- Strobing? Expected pulse rate, on-time & duty cycle?
- Is the part presented consistently in orientation & position?
- Any potential for ambient light contamination?

Ergonomics and Safety
- Man-in-the-loop for operator interaction?
- Safety related to strobing or intense lighting applications?
<table>
<thead>
<tr>
<th>Lighting Type</th>
<th>Partial Bright Field</th>
<th>Dark Field</th>
<th>Diffuse Axial Full Bright Field</th>
<th>Diffuse Dome Full Bright Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting Type</td>
<td>Ring, Spot</td>
<td>Angled Ring, Bar</td>
<td>Diffuse Box</td>
<td>Dome</td>
</tr>
<tr>
<td>No Specular</td>
<td>Negate Specular</td>
<td>Use Specular</td>
<td>Use Specular</td>
<td>Use Specular</td>
</tr>
<tr>
<td>When To Use</td>
<td>-Non specular</td>
<td>-Specular / Non</td>
<td>-Specular / Non</td>
<td>-Specular / Non</td>
</tr>
<tr>
<td></td>
<td>-Area lighting</td>
<td>-Surface / Topo</td>
<td>-Flat / Textured</td>
<td>-Curved surfaces</td>
</tr>
<tr>
<td></td>
<td>-May be used as a dark field light</td>
<td>-Edges</td>
<td>-Angled surfaces</td>
<td>-If ambient light issues</td>
</tr>
<tr>
<td>Requirements</td>
<td>-No WD limit</td>
<td>-Light must be very close to part</td>
<td>-Light close to part</td>
<td>-Light close to part</td>
</tr>
<tr>
<td></td>
<td>(limited only to intensity need on part)</td>
<td>-Large footprint</td>
<td>-Large footprint</td>
<td>-Large footprint</td>
</tr>
<tr>
<td></td>
<td>-Limited spot size</td>
<td>-Ambient light may interfere</td>
<td>-Ambient light minor</td>
<td>-Camera close to light</td>
</tr>
<tr>
<td></td>
<td>-Ambient light may interfere</td>
<td></td>
<td>-Beam splitter lowers light to camera</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-Spot size is ½ light inner diameter</td>
</tr>
</tbody>
</table>
Using Color Lighting to our Advantage
Using Color

Use Colored Light to Create Contrast

• Use Like Colors or Families to Lighten  (green light makes green features brighter)

• Use Opposite Colors or Families to Darken  (red light makes green features darker)
Consider how color affects both your object and its background!

White light will contrast all colors, but may be a contrast compromise.
Using Near IR and Near UV Light
All Light is seen differently by film, humans and CCDs
Infra-red (IR) light interacts with sample material properties, often negating color differences.
Near IR light can penetrate materials more easily because of the longer wavelength.
Red 660 nm light reveals the blue dot matrix printed bottle date & lot codes.
Near UV light when used w/ a matched UV excitation dye, illuminates codes and structural fibers.

Top Image Set: Diaper

Lower Image Set: Motor Oil Bottle
Near UV light fluoresces many polymers, including nylon.

- Top Image: UV Light, B&W CCD
- Lower Image: UV Light, Color CCD
Filters are useful too!

Blocking Ambient Light – Band Pass
Blocking Glare – Polarization
Avoiding Surface Glare w/o Polarization
Ambient Light: Any light, other than the vision-specific lighting that the camera collects.

- Overhead plant lighting
  Mercury, HP Sodium, Fluorescent Tubes

- Other nearby task lighting
  Incandescent, Fluorescent Tubes

- Indicator status lights

- Temporary lighting – construction, emergency

- Sunlight – Weather and time-dependent

- Interference from other nearby vision-specific lighting!
Controlling and Negating Ambient Light

Turn off the ambient contribution
  Most effective . . . Least Likely!

Overwhelm the ambient contribution w/ strobing
  Effective, but requires more cost and complexity

Build a shroud
  Very effective, but time-consuming, bulky and expensive

Control it with pass filters
  Very effective, but requires a narrow-band source light
Pass Filters in Machine Vision

- Pass filters exclude light based on wavelength.
- Reduce sunlight and mercury vapor light $4X$
- Reduce fluorescent light $35X$

Graphics courtesy of Midwest Optical, Palatine, IL
Pass Filters

- Top Image: UV light w/ strong Red 660 nm “ambient” light.

- Bottom Image: Same UV and Red 660 nm “ambient” light, with 510 nm Short Pass filter applied.
Avoiding Surface Glare

- Change Geometry – 3D spatial arrangement of Light, Sample, and Camera (preferred)
- Strobe to overwhelm glare from ambient sources
- Use polarization filters (least preferred)

Courtesy Wikimedia Commons
Avoiding Surface Glare

3-D Reflection Geometry: Light - Sample - Camera
Polarizing Filters in Machine Vision

Coaxial Ring Light
- w/o Polarizers
- w/ Polarizers

Off-Axis Ring Light
- w/o Polarizers

Coaxial Ring Light
- w/o Polarizers
- w/ Polarizers

Welch's
- w/ Polarizers
Polarizing Filters in Machine Vision

Back Light - No Polarizer

Back Light - No Polarizer
Polarized backlighting is best used to detect internal anisotropy in transparent materials.
Standard Lighting Method

- Determine the Exact Features of Interest
- Analyze Part Access / Presentation
  - Clear or obstructed, Moving / Stationary
  - Min / Max WD range, Sweet Spot FOV, etc.
- Analyze Surface Characteristics
  - Texture
  - Reflectivity / Specularity
  - Effective Contrast – Object vs. background
  - Surface flat, curved, combination
- Light Types and Applications Techniques Awareness
  - Rings, Domes, Bars, ADIs, Spots, Controllers
  - Bright Field, Diffuse, Dark Field, Back Lighting
- Determine Cornerstone Issues
  - 3-D Geometry, Structure, Color & Filters
- Ambient Light Effects / Environmental Issues
Summary and Conclusions

Develop the lighting solution early on in the vision system process
Determine appropriate light geometry techniques
Consider reflection geometry
Be aware of and block ambient light
Consider camera wavelength sensitivity
Use monochrome light for high-accuracy gauging
Remember that light MAY interact differently with respect to surface texture, color and composition
Make the lighting solution robust
Need more help? – Call your lighting professional!!
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