Basic Lighting Techniques for Machine Vision

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Advanced illumination
1) Understand that Dedicated, Object Appropriate Lighting is critical for virtually all MV Applications.
2) Identify 9 “Guidelines” for applying MV Lighting.
3) Name 6 Lighting Techniques and describe when each may be appropriate.
4) Identify the 6 steps in the “Vision Lighting Design Method.”
5) Explain “Spectral Range” as applied to vision cameras.
6) List the 4 cornerstones of Vision Illumination.
7) Describe 4 ways light can interact with your object.
8) Identify the 3 primary inspection physical environment constraints.
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

2) Familiarity with the 4 (Contrast Enhancement) Cornerstones of Vision Illumination:
   - Geometry (Light Direction and Nature at the Source)
   - Structure (pattern)
   - Color (wavelength)
   - Filtering (Light Characteristics)

3) Detailed Analysis of:
   - Sample – Light Interactions with respect to your unique object
   - Immediate Inspection Environment – Physical constraints and
     requirements (critical for Robotics Apps)
What we really require is control of the lighting environment!

Why?

- Part (Object Feature) inspection & system appropriate lighting
- To the extent possible, standardization of components, techniques, system implementation and operation
- Reproducibility of inspection results
- Robustness to handle sample variations of “all types”
Topics

- Brief Review of Light as Applied to Machine Vision
- Compare / Contrast Lighting Sources
- Review Light / Sample and Light / Camera Interactions
- Review Basic Lighting Geometry Techniques - Examples
  - Directional Bright Field vs. Dark Field
  - Back Lighting
  - Preview of Diffuse Lighting Techniques
- More Applications Examples
- Preview of Filtering: Pass and Polarization
- Preview of Color Lighting Analysis
- Preview of Near IR and UV Vision Light
- Lighting for Robotics (time and interest permitting)
Machine Vision Definitions

- Machine Vision is the computer-based characterization of a digital image from an electronic sensor.
- A digital image is a 1-D or 2-D array of picture elements (pixels), each having an (X,Y) location and an intensity, typically 0 – 255 gray scales, or 8-bit contrast.
- **Contrast** is the visible intensity difference between dark (near 0) and light (near 255) pixels.
- In its most derivative form, then we are characterizing light contrast patterns from an object.
Vision Lighting Development

Art?

Science??

Or both?

Image Courtesy NASA - HST

Images Courtesy Wikimedia Commons Public Domain
Vision Lighting Development

- 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
Object Feature-Appropriate Lighting

What is it?

The **light type & technique**, tailored for the specific application, that allows the vision system do its job **accurately, robustly AND reproducibly**.

Why is it important to Machine Vision?

1) Provides for an accurate, consistent & robust lighting environment.
2) Saves development time, effort & resources.

How do I get there?

1) Determine object features that uniquely ID parts as “bad” or “good” (*a.k.a.* – “features of interest”)
2) Design lighting that creates consistent contrast between the object’s features of interest and background.
3) Test the lighting method on many “bad” & “good” objects.
Review of Light for Vision Illumination
Characterizing Light for Vision

Light: Photons propagating as a transverse electromagnetic energy wave - characterized by:

- **Measured “Intensity”**: Radiometric and Photometric
- **Frequency**: Varies inversely with wavelength (Hz – waves/sec)
- **Wavelength**: Expressed in nanometers (nm) or microns (µm)

Photons:

Energy packets exhibiting properties of waves and particles.

100,000 nm
Decreasing Frequency  →  Increasing Wavelength
Decreasing Photon Energy  →  Increasing Photometric Output
Increasing Penetration Depth*

*For some sample materials, absorption bands may block longer wavelength penetration.
Characterizing Light for Vision

Properties when interacting with media (objects):

- **Diffusion** (“dispersal”) through media.
- **Reflection** – When not viewing a light source directly, light must interact with objects for us to see it! (Fundamental)
- **Refraction** (apparent bending) through media – longer wavelengths refract less (\textit{i.e.} red light refracts < violet light).
- **Diffraction** (“bending”) around object edges (not that important).

![Angle of Dispersion](source)

\[ \phi_1 = \phi_2 \]

Courtesy Wikimedia Commons
Vision Lighting Sources
Vision Lighting Sources

LED - Light Emitting Diode
Quartz Halogen – W/ Fiber Optics
Fluorescent
Xenon (Strobing)
LED Types

T1 ¾, The Standard
Courtesy Sun LED

Surface Mount LEDs
Courtesy Sun LED

High Current LEDs
Courtesy Cree and Philips
Light - Sample Interaction
Total Light In =
Reflected + Absorbed + Transmitted + Emitted (fluorescence) Light

- Measured Irradiance/Illuminance falls off as the inv. sq. of the distance \( (I = 1 / r^2) \)
- \( 2X (WD) = \frac{1}{4} \) the “intensity”
Light Interaction

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

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

*Critical Parameters for Robotics Apps

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

You cannot solve vision problems working in a vacuum!
Ambient Light

Any light other than the vision-specific lighting that the camera collects.

Controlling and Negating Ambient Light

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

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

Overwhelm the ambient contribution w/ high-power lighting (Continuous-on or Strobe over-drive)
   Effective, but requires more cost and complexity

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

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

Graphics courtesy of Midwest Optical, Palatine, IL
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.
Lighting Contrast

It’s All About (creating) **Contrast**

Contrast!!

1) Maximum contrast
   • features of interest *(Signal)*

2) Minimum contrast
   • features of no interest *(Noise)*

3) Minimum sensitivity to normal variations *(ROBUST)*
   • minor part differences
   • presence of, or change in ambient lighting
   • sample handling / presentation differences

Points 1 & 2 might solve some apps; # 3 can be critical!
Lighting Cornerstones

How to change contrast?

Change Light Direction w/ Respect to Sample and Camera (Geometry)
  - 3-D spatial relationship - object, light & camera

Change Light Pattern (Structure)
  - Light Head Type: Spot, Line, Dome, Sheet
  - Illumination Type: B.F. - D.F. - Diffuse - B.L.

Change Spectrum (Color / Wavelength)
  - Projecting Monochromatic, white vs. object / camera response
  - Projecting Warm vs. cool color family light – object vs. background

Change Light Character (Filtering)
  - Affecting the wavelength or character of light collected by the camera
Light - Pickup Device Interaction
Sensors and Wavelength

Wavelength (nm)

<table>
<thead>
<tr>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
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<tbody>
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</table>

Absolute QE (%)

IR Enhanced Analog
Digital Interline Transfer
Standard Analog
CMOS
UV Enhanced Analog
Human Scotopic (Night)
Human Photopic
IR Block (Short Pass)
Lighting Geometry Techniques
Basic Lighting Techniques

1 - Partial Bright Field

2 - Dark Field

3 - Back Lighting
Advanced Lighting Techniques

- 4- Co-Axial Diffuse*
- 5 - Diffuse Dome
- 6 - Flat Diffuse

Full Bright Field

Collimated
- Co-axial
- Back Lighting

Multi-Axis / Combo
- Dome + Dark Field
- Bright and Dark Field
- Addressable Rows

Structured
- Laser/LED grids, lines
- Focused Linear

* It should be noted that strictly defined, Co-axial Diffuse lighting is a partial bright field Technique.
Bright Field vs. Dark Field

Typical On-Axis Ring Light – Sample Geometry

Bright Field

Dark Field
Full Bright Field Lights in White Area

Partially Bright Field Lights in White Area

Dark Field Lights in Grey Areas

Mirrored Surface

Scratch
**Bright Field vs. Dark Field Light**

**Bright Field**
- Specular surfaces reflect glare if light is high-angle
- Diffuse, flat and smooth surfaces reflect evenly

**Dark Field**
- Emphasize Height, Edges
- Diffuse Surfaces Bright
- Flat Polished Surfaces Dark
- Shape and Contour Enhanced
Dark Field Example

- Angled light – 45 degrees or less
- Used on highly reflective surfaces
- OCR or surface defect applications
Dark Field Light

- Emphasize Height Changes
- Diffuse Surfaces are Bright
- Flat Polished Surfaces are Dark
- Shape and Contour are Enhanced
Back Lighting

- Edge or hole detection

- Useful on translucent materials
  - Liquid fill levels
  - Glass/plastic cracks

- Part P/A

- Vision-Guided robotics – Pick and Place

- Gauging – Including high-accuracy measurements
**Light Diffusion & Diffraction:**
- Multiple angle light from back light diffuser
- Bending around obstacles

\[ \Theta = \frac{\lambda}{D}, \text{ where } \Theta \text{ is the diffraction angle and } D \text{ is opening width (} \Theta_1 > \Theta_2 ) \]

**High-accuracy gauging:**
- Use monochromatic light
- Shorter wavelengths best

Use collimation – parallel rays

Longer \( \lambda \) light may penetrate some objects better
Small Bottle – Determine Fill Level
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
End of Part 1 = Break Time!

(Please be back in 10 mins . . .)
Diffuse Dome

- Similar to the light on an overcast day.
- Creates minimal glare.
Diffuse Dome

- Surface texture and detail are de-emphasized
- Contrast is de-emphasized
- Useful for curved shiny parts
- Opposite effect of Dark Field
Co-Axial Diffuse Illumination

- Light directed at beam splitter
- Used on non-curved, reflective objects
Co-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 Co-Axial)
### Advantages - Disadvantages

<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>
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<tbody>
<tr>
<td><strong>When To Use</strong></td>
<td>Ring, Spot, Bar</td>
<td>Angled Ring, Bar</td>
<td>Diffuse Box</td>
<td>Dome Flat Diffuse</td>
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<tr>
<td>-Non specular</td>
<td>-Non Specular</td>
<td>-Non Specular</td>
<td>-Non Specular</td>
<td>-Non Specular</td>
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<tr>
<td>-Area lighting</td>
<td>-Surface / Topo</td>
<td>-Flat / Textured</td>
<td>-Curved surfaces</td>
<td></td>
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<tr>
<td>-May be used as a dark field light</td>
<td>-Edges</td>
<td>-Angled surfaces</td>
<td>-If ambient light issues</td>
<td></td>
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<tr>
<td><strong>Requirements</strong></td>
<td>-No WD limit (limited only to intensity need on part)</td>
<td>-Light must be very close to part</td>
<td>-Light close to part</td>
<td>-Light close to part</td>
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<tr>
<td></td>
<td>-Large footprint</td>
<td>-Large footprint</td>
<td>-Large footprint</td>
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<tr>
<td></td>
<td>-Limited spot size</td>
<td>-Ambient light minor</td>
<td>-Ambient light minor</td>
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<tr>
<td></td>
<td>-Ambient light may interfere</td>
<td>-Beam splitter lowers light to camera</td>
<td>-Beam splitter lowers light to camera</td>
<td>-Spot size is ½ light inner diameter</td>
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</tbody>
</table>
Technique vs. Object Surface

Surface Reflectivity

Matte

Mixed

Mirror Specular

Flat

Axial Diffuse

Geometry
Independent
Area

Uneven Topography

Bright Field

Flat Diffuse

Diffuse Dome / Cylinder

Dark Field

Curved

Surface Texture / Shape
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
- Object 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?
Applications Examples
Printing beneath cellophane wrapped package

Co-Axial Diffuse Illuminator
Recessed metal part
Reflective, textured, flat or curved surface

Stamped Date Code

Bright field spot light
Avoiding Surface Glare

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

- w/o Polarizers
- w/ Polarizers

Up to 2 ½ f/stops more open!
Avoiding Surface Glare

3-D Reflection Geometry: Light - Sample - Camera
Using Color and Wavelength
Create Contrast with Color

Use Monocolor Light to Create Contrast

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

Use Opposite Colors or Families to Darken
(red light makes green features darker)
Create Contrast with Color

Consider how color affects both your object and its background!

White light will contrast all colors, but may be a compromise.
## Wavelength vs. Composition

<table>
<thead>
<tr>
<th></th>
<th>UV</th>
<th>B</th>
<th>G</th>
<th>R</th>
<th>IR</th>
<th>RGB</th>
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<td>Doped w/ UV Fluorescing Agent</td>
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<td>Dark Rubber</td>
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<tr>
<td>Dark Plastics</td>
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<td>X</td>
<td></td>
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<td></td>
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<tr>
<td>Transparent Plastics / Glass</td>
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<td>X</td>
<td>X</td>
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<tr>
<td>Semi-metallic</td>
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<tr>
<td>Metallic</td>
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<td>Mixed Color Parts</td>
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<td>General Purpose</td>
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<td>Ambient Light Problems</td>
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<tr>
<td>Strobe / Ergonomic Issues</td>
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Imaging with Near IR and UV Light
Vision Lighting Spectrum

Graphics courtesy of Midwest Optical, Palatine, IL
Imaging with Near IR (NIR)

- Infra-red (IR) light interacts with sample material properties, often negating color differences.

White light – B&W Camera

IR light – B&W Camera
Near IR light can penetrate materials more easily because of the longer wavelength.
Imaging with UV Light

Fluorescing Printing

Fluorescing Polymers (nylon)

Under 355 nm UV and Strong Ambient

Application of a Short Pass Filter
Review and Summary
Vision Lighting Design Method

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

1) Coordinated Lighting & Optics are crucial – when properly selected, they provide the foundation for the MV system.

2) Develop the lighting solution early in the vision system design process – on the bench first, if necessary.

3) Dedicated Lighting = Control of the Lighting Environment.

4) Develop Object Feature-Appropriate Lighting.

5) Apply the 4 Cornerstones for enhancing contrast of features.

6) Be aware of and block ambient light.

7) Consider that light MAY interact differently w/ respect to surface texture, color, composition and incident wavelength.

8) Make the lighting solution robust AND reproducible.

9) Understand the Inspection Environment w/ respect to Physical Constraints, Object Characteristics and Ergonomic / Safety aspects.
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