Basic Lighting Techniques for Machine Vision

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Class Objectives

- Provide for a basic understanding of light as applied to machine vision illumination.
- Learn and apply basic rules-of-thumb for solving lighting applications based on a more objective analysis of the problem.
- Generate awareness of the flexibility of lighting solutions and techniques available.
- Suggest a “Standard Lighting Method”.

Class Objectives

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
   - Structure (pattern)
   - Color (wavelength)
   - Filtering

3) Detailed Analysis of:
   - Sample – Light Interactions with respect to your unique sample
   - Immediate Inspection Environment – Physical constraints and requirements (critical for Robotics Apps)

Objectives of Vision Lighting

- Proper lighting environment?
- Consistent lighting environment?
- But what is appropriate for you, may not be for others!
- 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, system implementation and operation
  - Reproducibility of inspection results
  - Robustness to handle 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
- Added Content on Robotics (time and interest permitting)

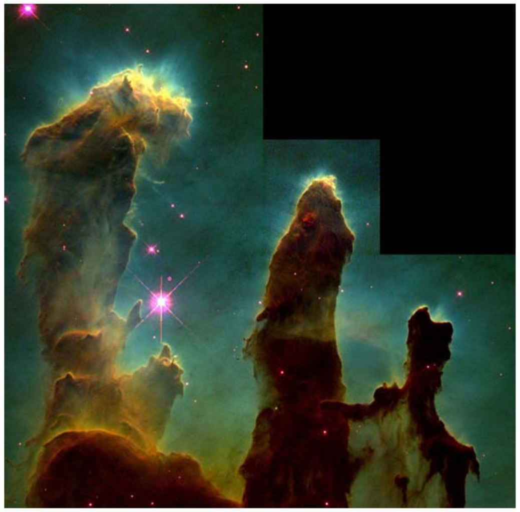
Machine Vision Definitions

- 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 difference between dark (near 0) and light (near 255) pixels.
- In its most derivative form, then we are characterizing light contrast patterns from a sample.

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

Sample-Appropriate Lighting

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

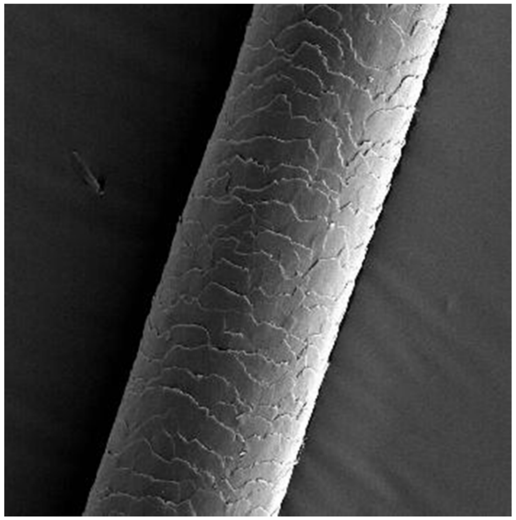
- Critical for a successful inspection
- Provides for a quality, consistent & robust lighting environment
- Saves development time, effort & resources

Review of Light for Vision Illumination

Characterizing Light for Vision

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

- Frequency: Varies inversely with wavelength (Hz – waves/sec)
- Measured Photon Intensity: Radiometric and Photometric (more later)
- Wavelength: Expressed in nanometers (nm) or microns (um)

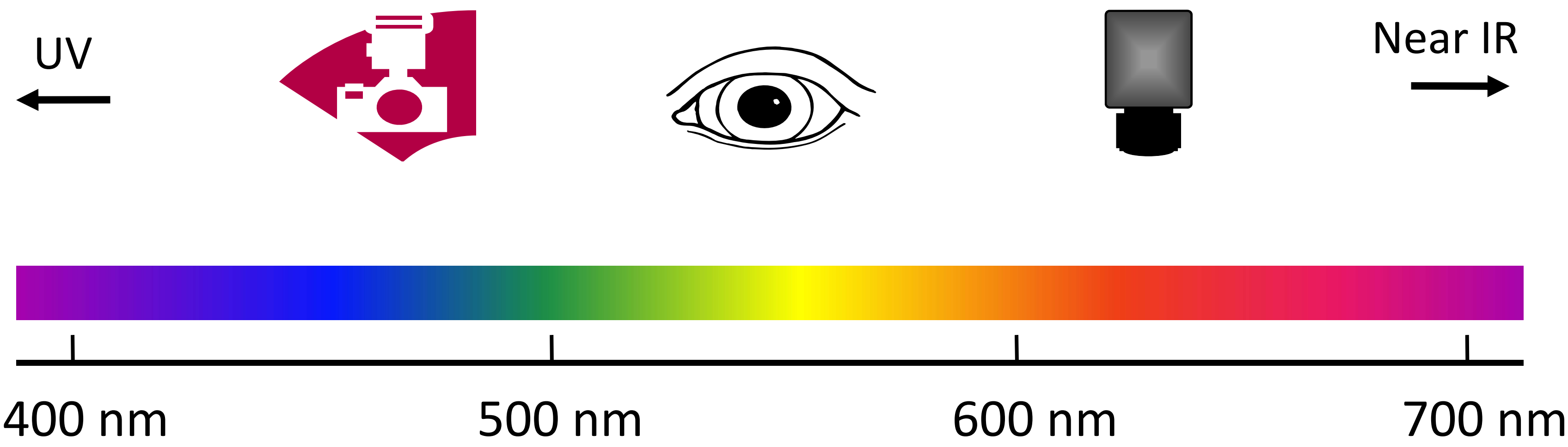


100,000 nm

Photons:

Energy packets exhibiting properties of waves and particles.

Visible Light Spectrum



Human Visible Range

Decreasing Frequency →

Decreasing Photon Energy →

Increasing Wavelength →

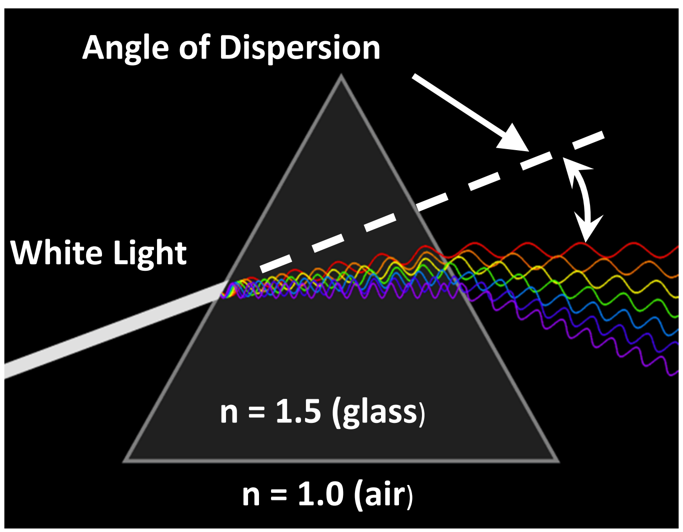
Increasing Photometric Output →

Increasing Penetration Depth →

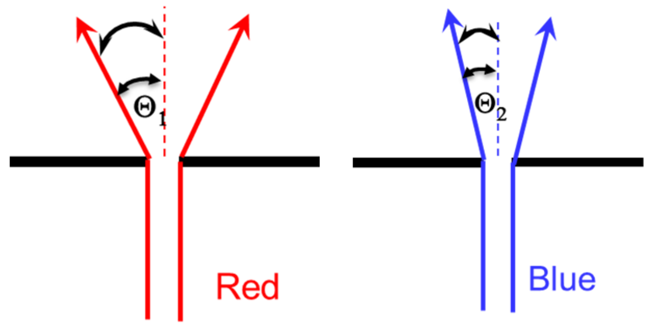
Characterizing Light for Vision

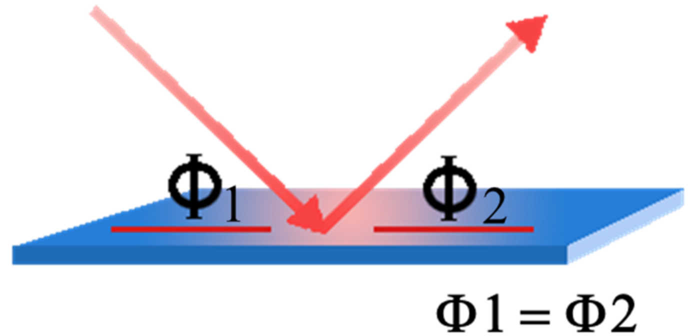
Properties when interacting with media (samples):

- Diffraction (bending) around edges – longer wavelengths diffract more.
- Reflection – Light must interact (mostly reflect) with objects for us to see it!
- Refraction (dispersion) through media – longer wavelengths refract less (i.e., - red light refracts < violet light).



Courtesy Wikimedia Commons





Vision Lighting Sources

Vision Lighting Sources

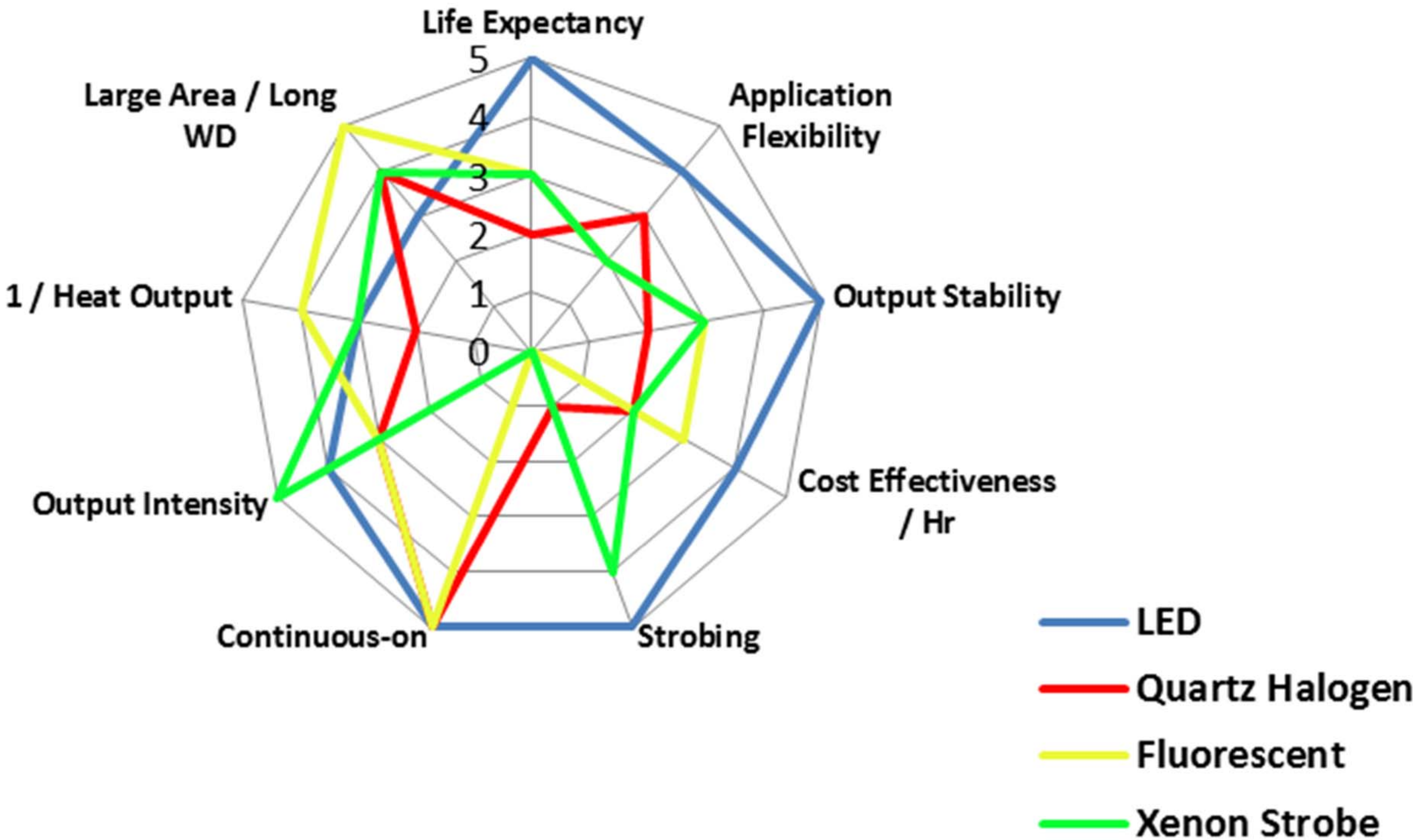
LED - Light Emitting Diode

Quartz Halogen – W/ Fiber Optics

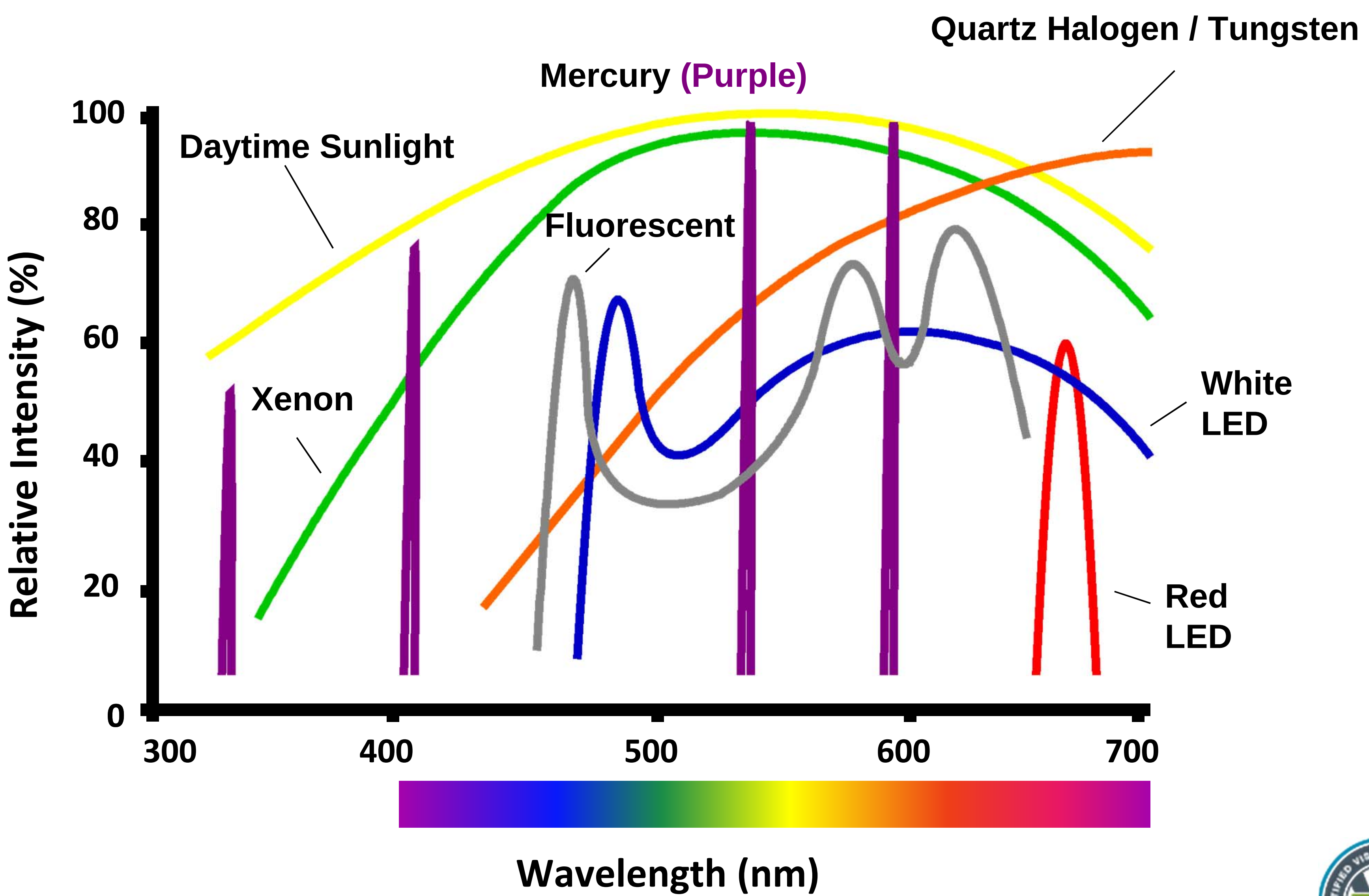
Fluorescent

Xenon (Strobing)

Primary Vision Light Sources



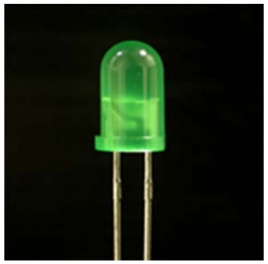
Intensity vs. Wavelength



LED Types

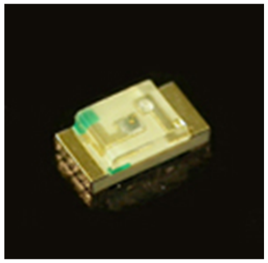
T1 ¾, The Standard

Courtesy Sun LED



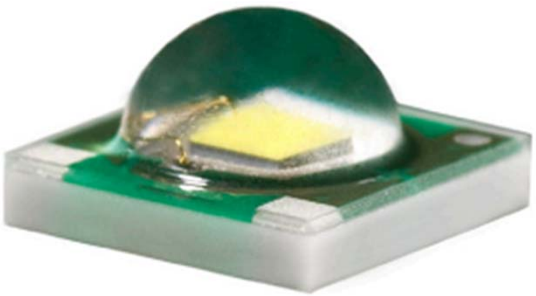
Surface Mount LEDs

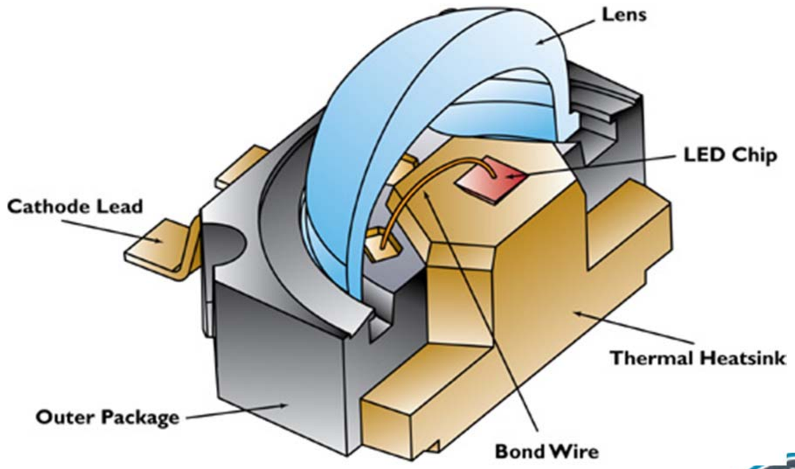
Courtesy Sun LED



High Current LEDs

Courtesy Cree and Philips



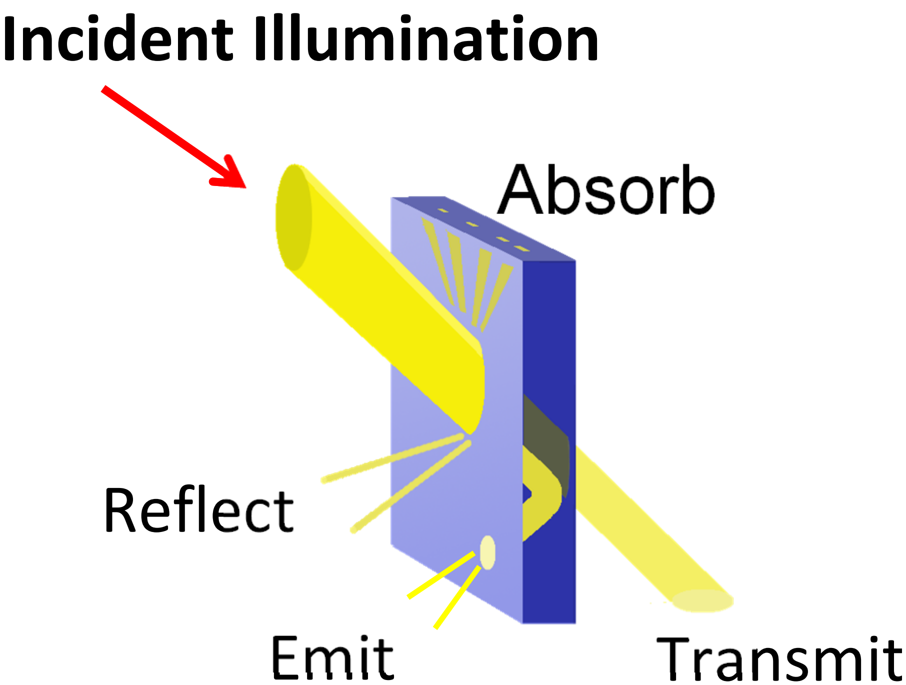


Light - Sample Interaction

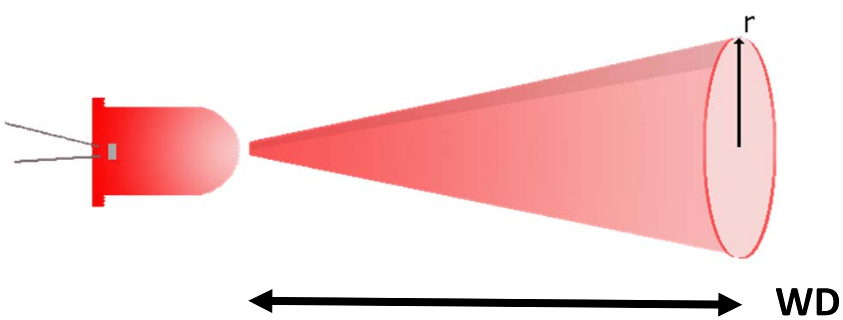
Light - Sample Interaction

- Total Light In =

  Reflected + Absorbed + Transmitted + Emitted Light



- Intensity falls off as the inv. sq. of the distance ($I = 1 / r^2$)
- 2X (WD) = ¼ the intensity



Light Interaction

Convergence of Concepts

(Sample – Light – Lens**)

Contrast

Resolution

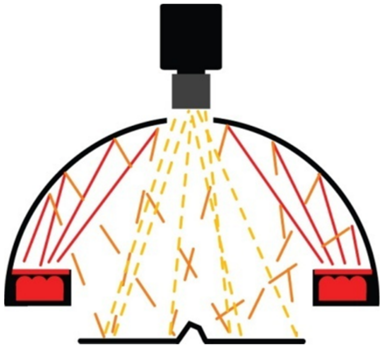
Spatial, Spectral

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/ strobing

Effective, but requires more cost and complexity

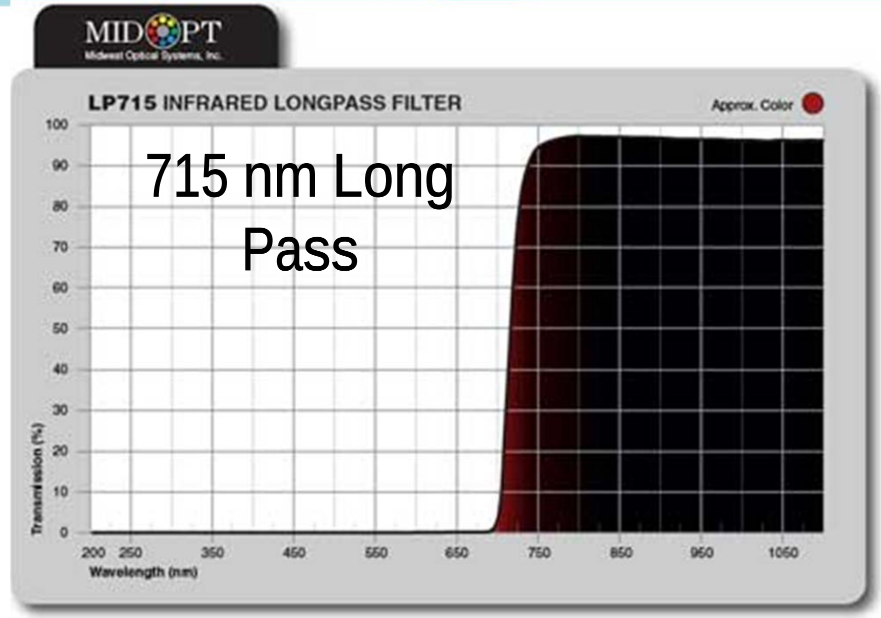
Control it with pass filters

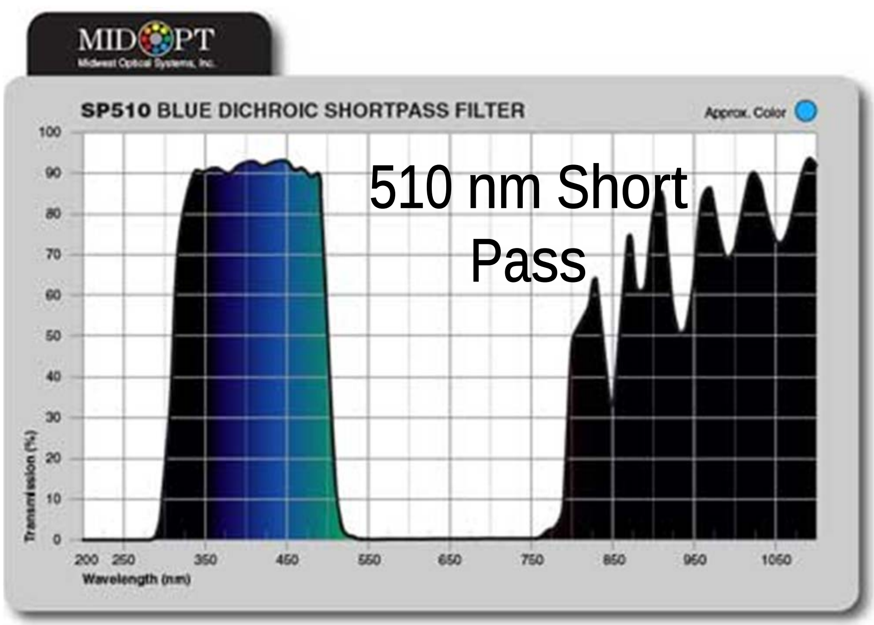
Very effective, but requires a narrow-band source light

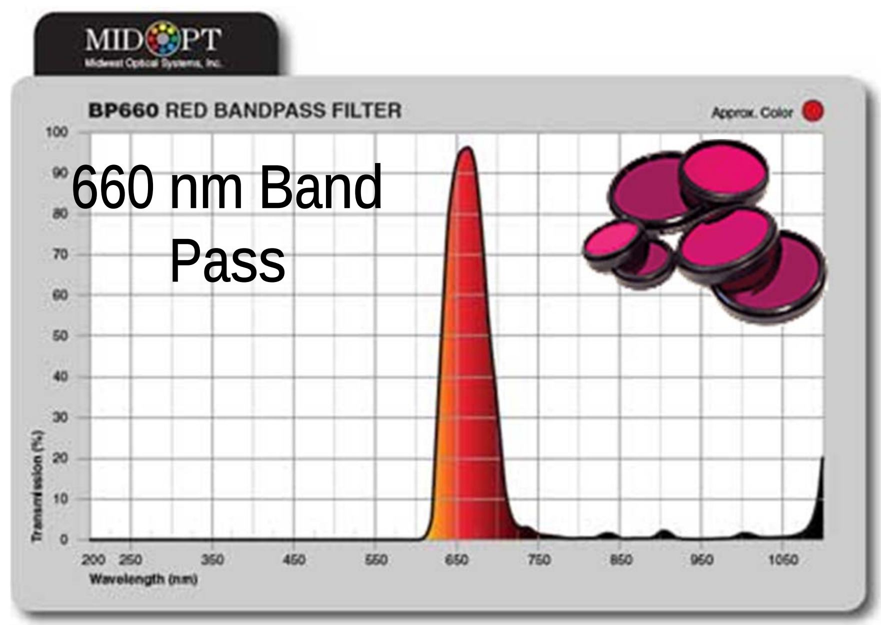
Pass Filters in Machine Vision

- 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

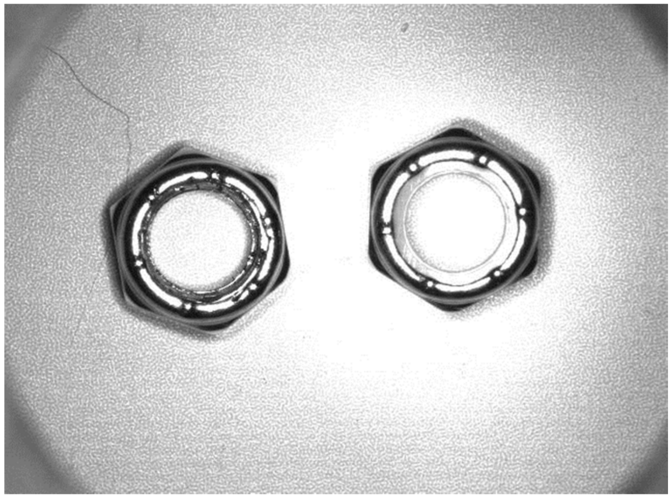




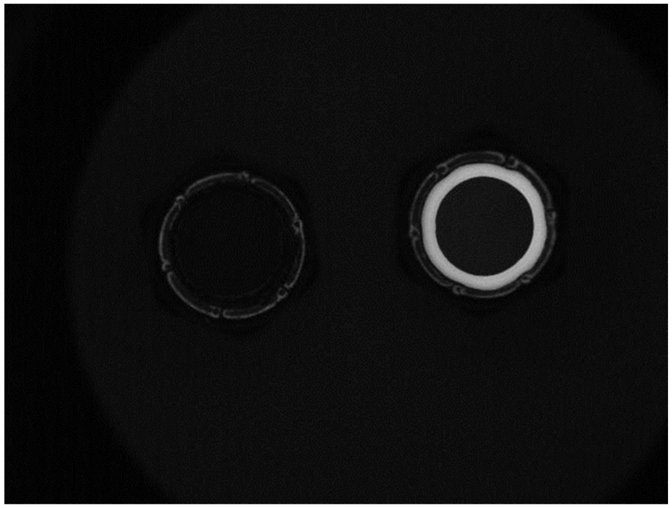


Pass Filter Example

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 - sample, 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)

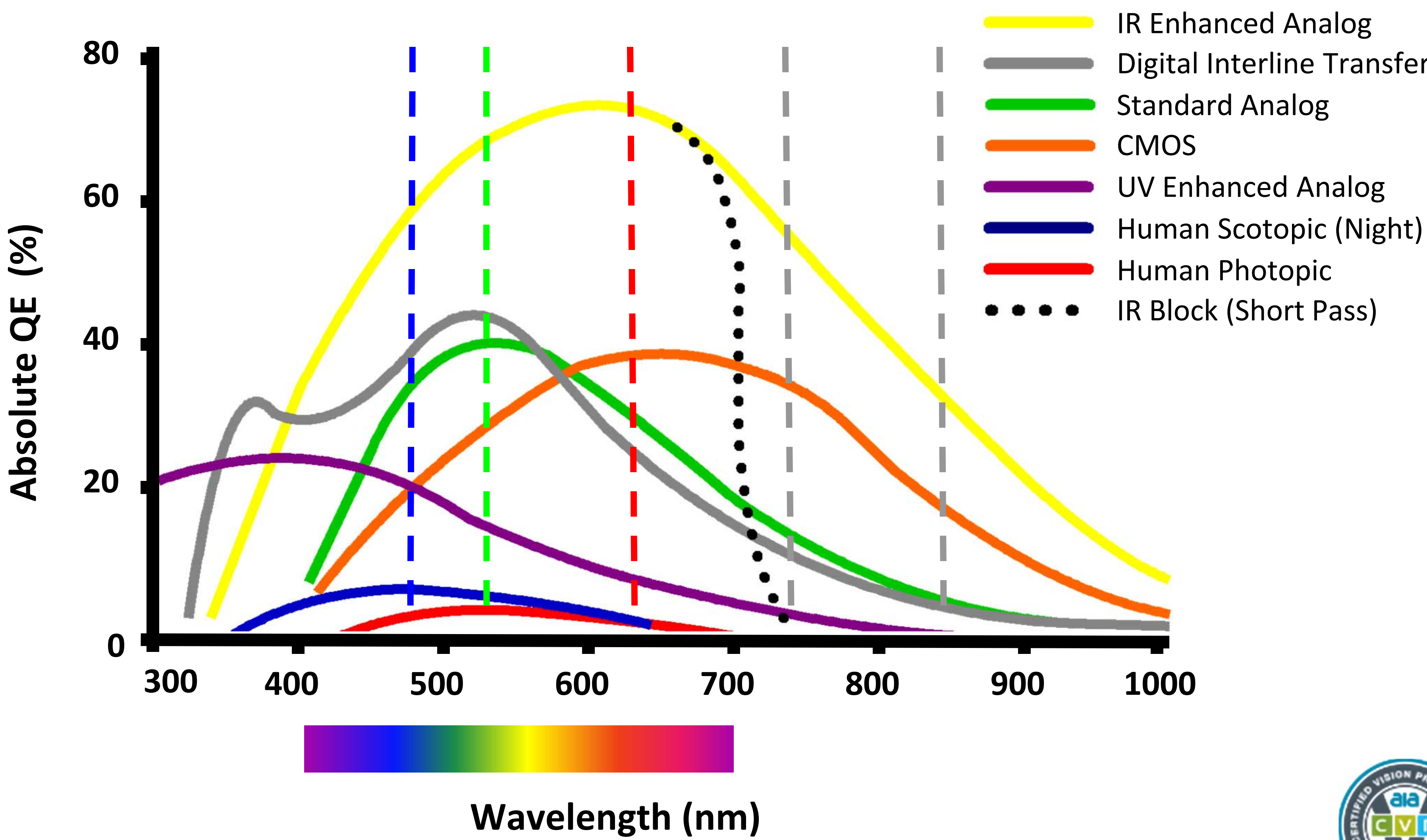
- Monochrome, white vs. sample / camera response
- Warm vs. cool color families – object vs. background

Change Light Character (Filtering)

- Affecting the wavelength or character of light to the camera

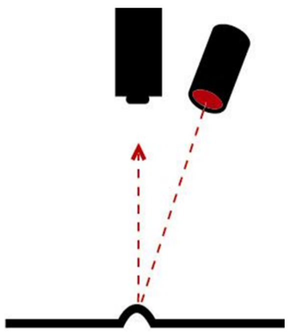
Light - Pickup Device Interaction

Sensors and Wavelength

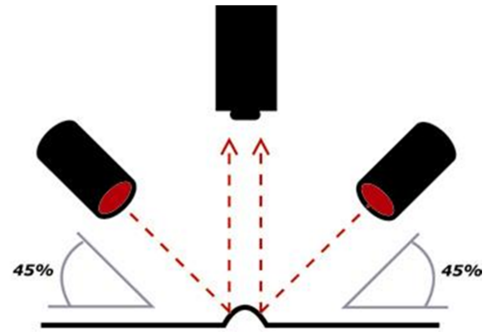


Lighting Geometry Techniques

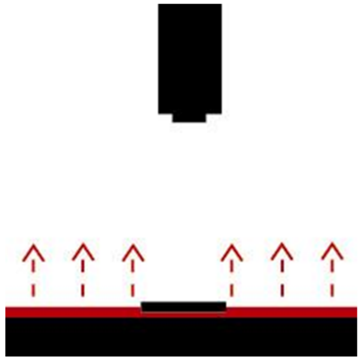
Basic Lighting Techniques



Partial Bright Field

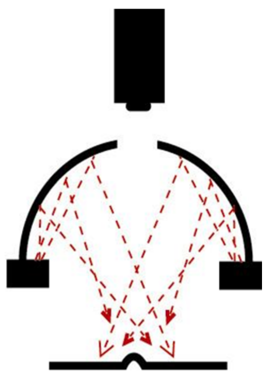


Dark Field

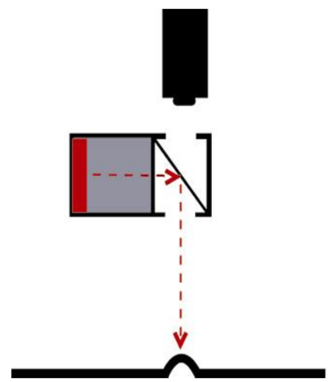


Back Lighting

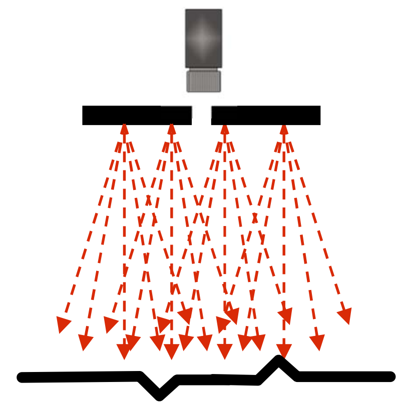
Advanced Lighting Techniques



Diffuse Dome



Axial Diffuse



Flat Diffuse

Full Bright Field

Collimated

Co-axial
Back Lighting

Multi-Axis / Combo

Dome + Dark Field
Bright and Dark Field
Addressable Rows

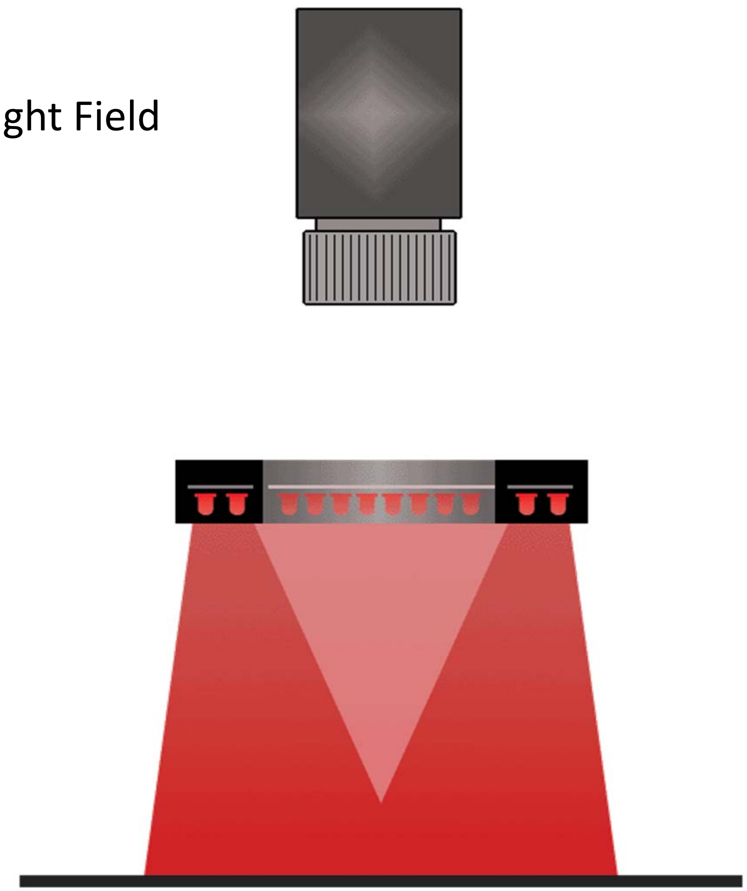
Structured

Laser/LED grids, lines
Focused Linears

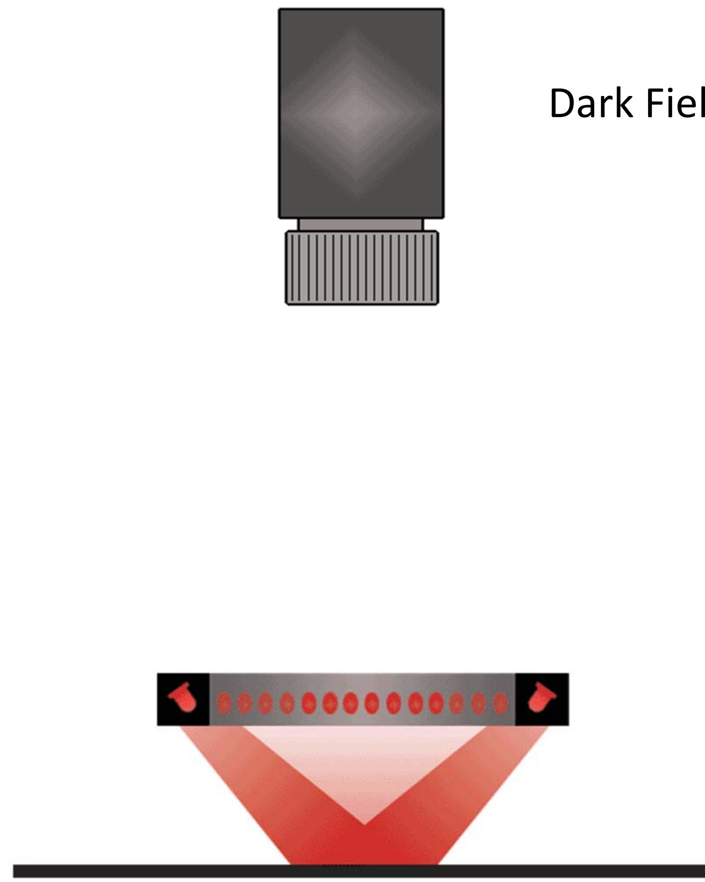
Bright Field vs. Dark Field

Typical Co-axial Ring Light – Sample Geometry

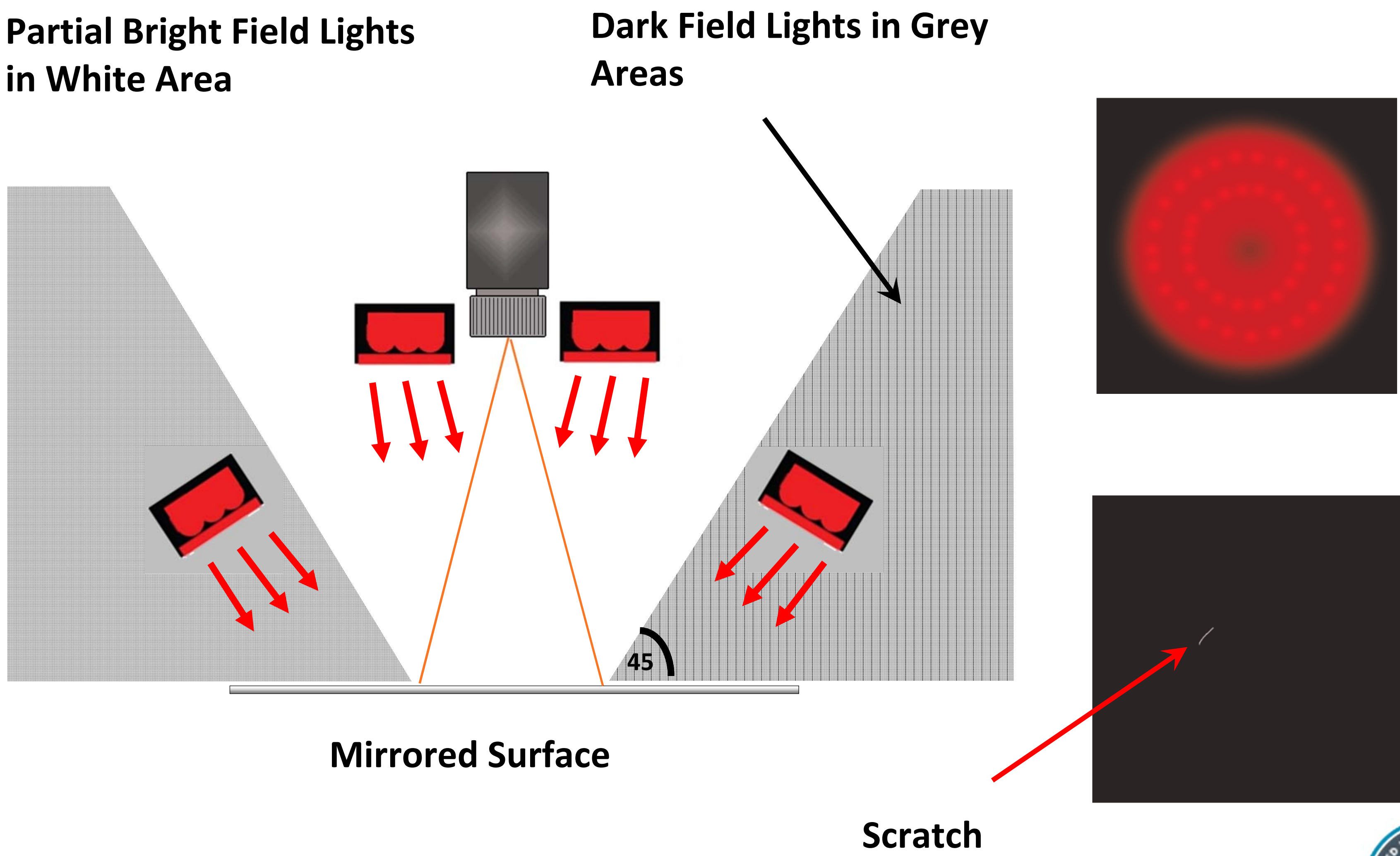
Bright Field



Dark Field



Bright Field vs. Dark Field



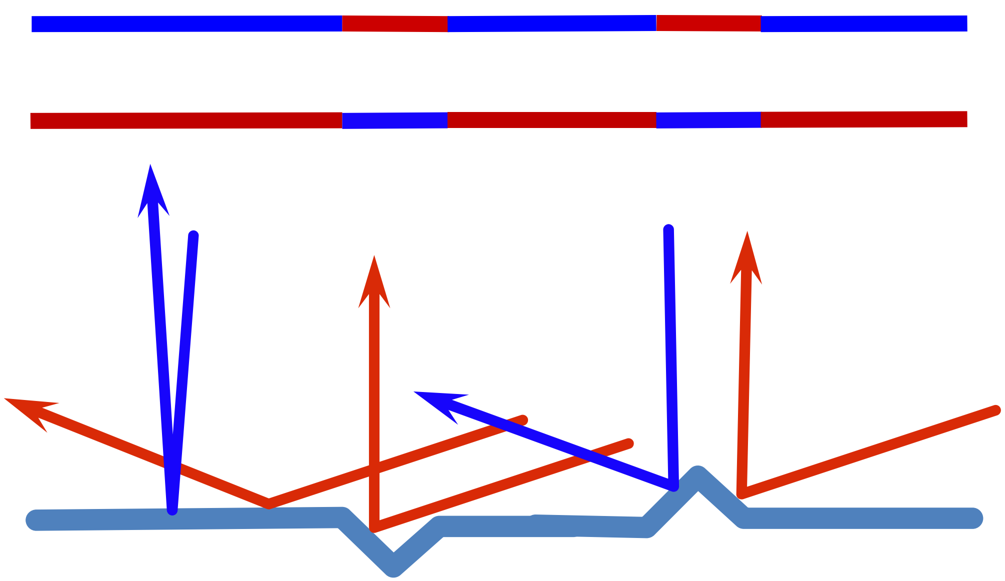
Bright Field vs. Dark Field Light

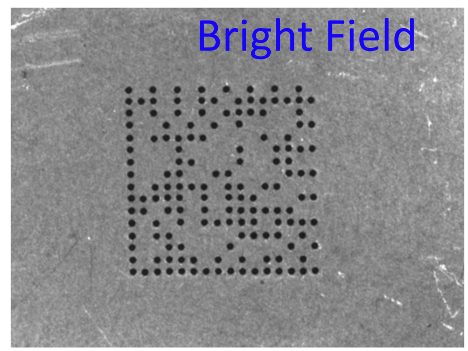
Bright Field

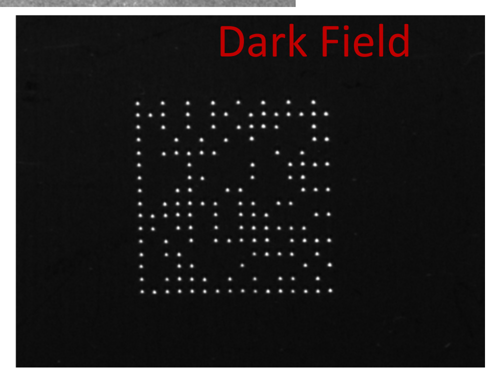
- Specular surfaces reflect glare if light is high-angle
- Diffuse, flat and smooth surfaces reflect evenly

Dark Field

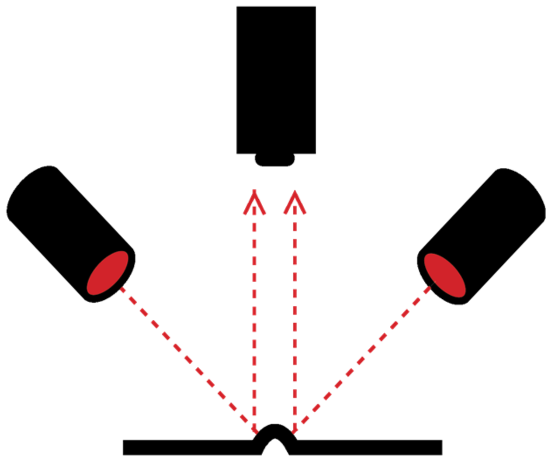
- Emphasize Height, Edges
- Diffuse Surfaces Bright
- Flat Polished Surfaces Dark
- Shape and Contour Enhanced



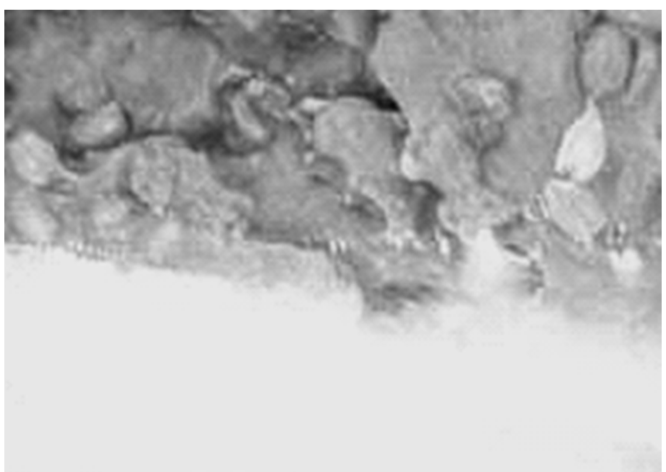


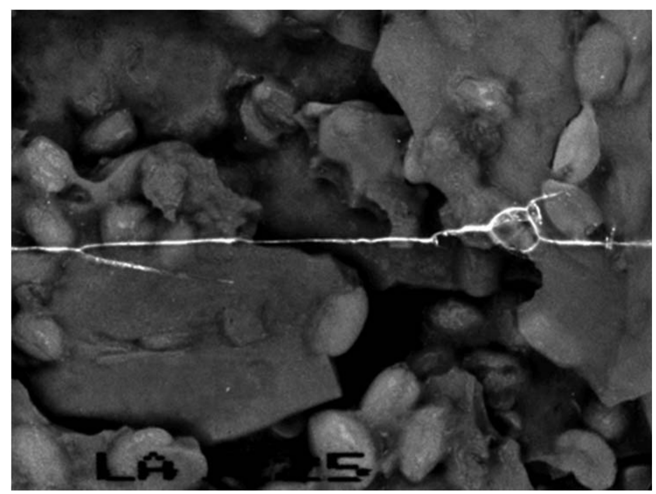


Dark Field Example



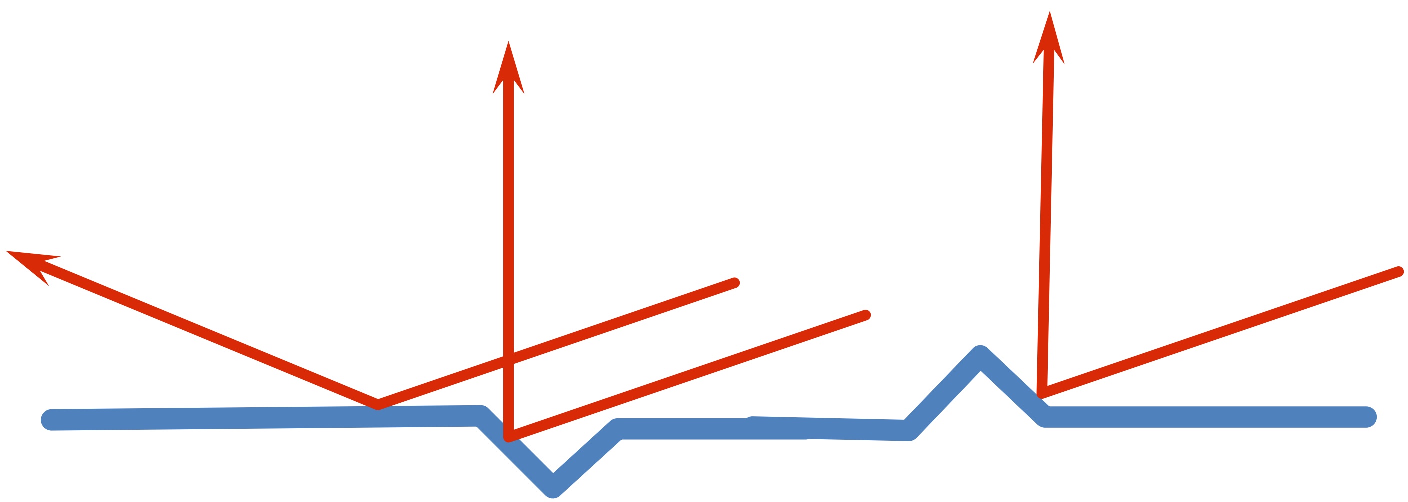
- Angled light – 45 degrees or less
- Used on highly reflective surfaces
- OCR or surface defect applications



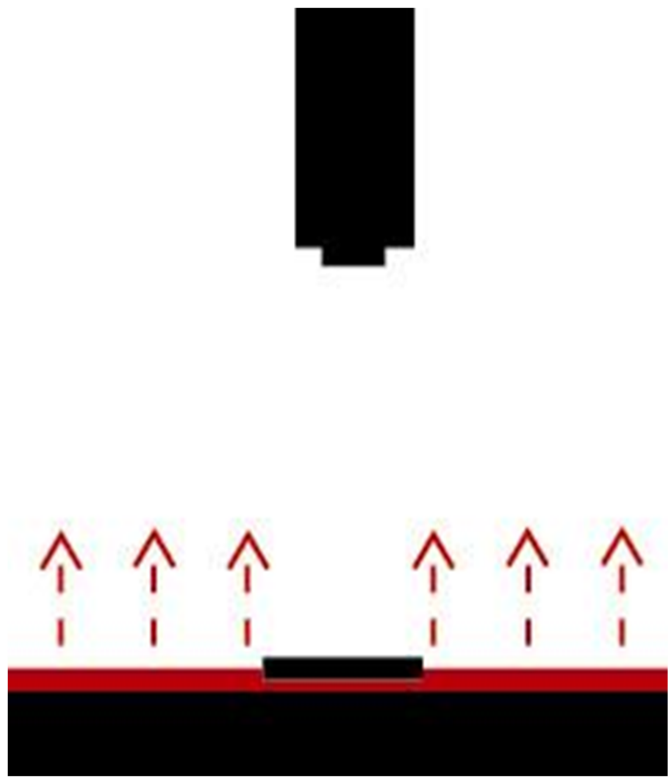


Dark Field Light

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

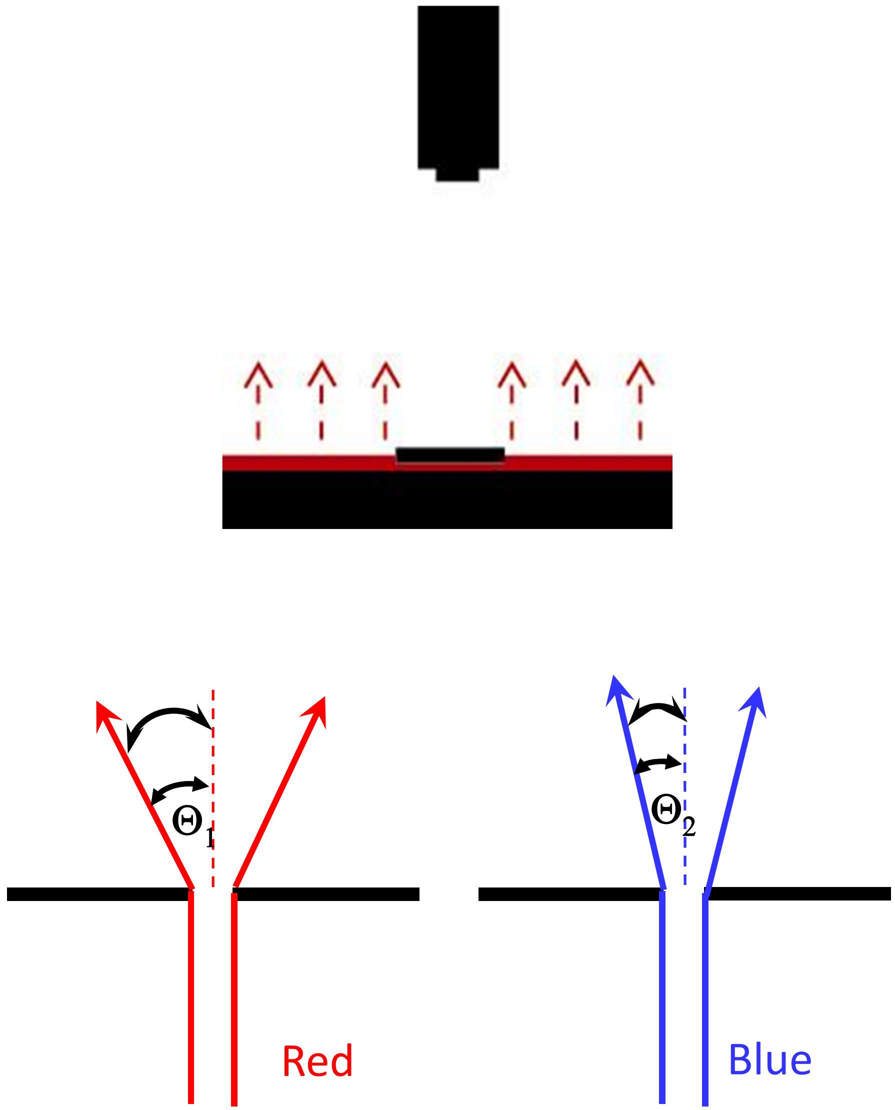


Back Lighting



- 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

Back Lighting



Light Diffraction:

Bending around obstacles

$\Theta = \lambda / D$, where Q is the diffraction angle and D is opening width ($\Theta_1 > \Theta_2$)

High-accuracy gauging:

Use monochrome light

Shorter wavelengths best

Use collimation – parallel rays

Longer λ light penetrates samples better

Back Lighting Example

Small Bottle – Determine Fill Level

Consider colors and materials properties also.

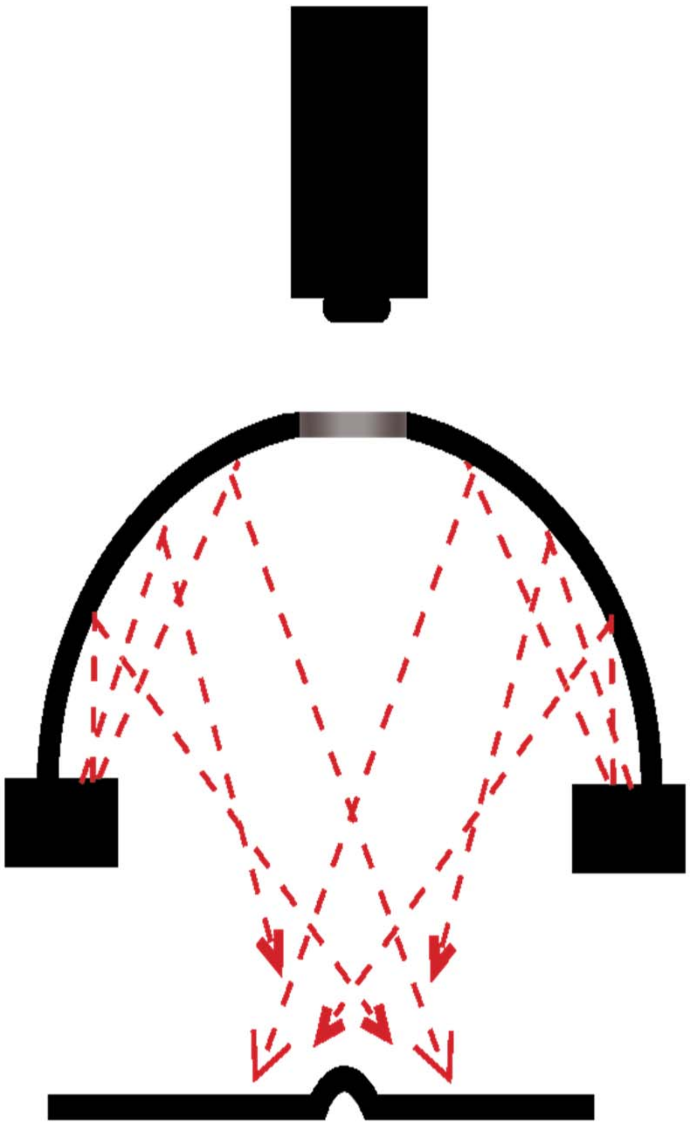
Longer wavelength isn't always best for penetration!

Collimated Backlight Illumination

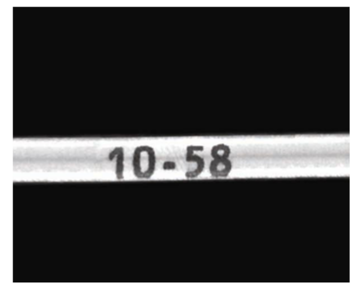
End of Part 1 = Break Time!

(Please be back in 10 mins . . .)

Diffuse Dome



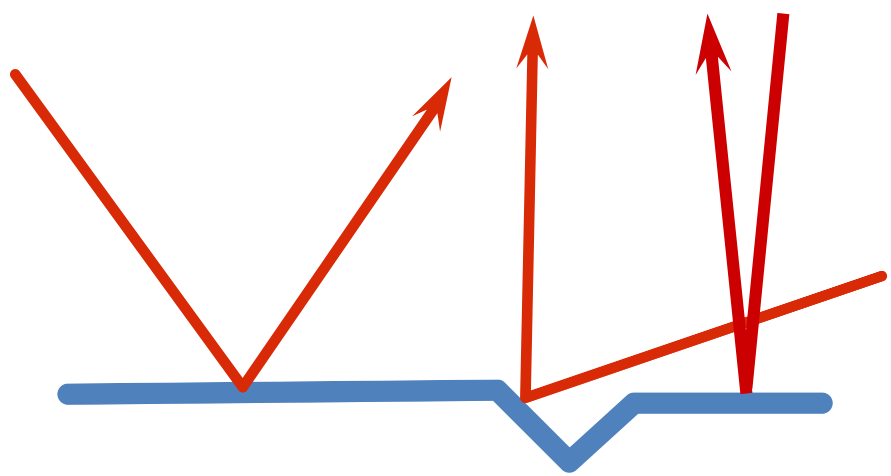
- Similar to the light on an overcast day.
- Creates minimal glare.



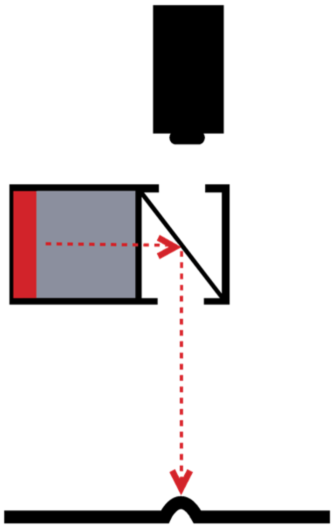
Diffuse Dome

Full Bright Field

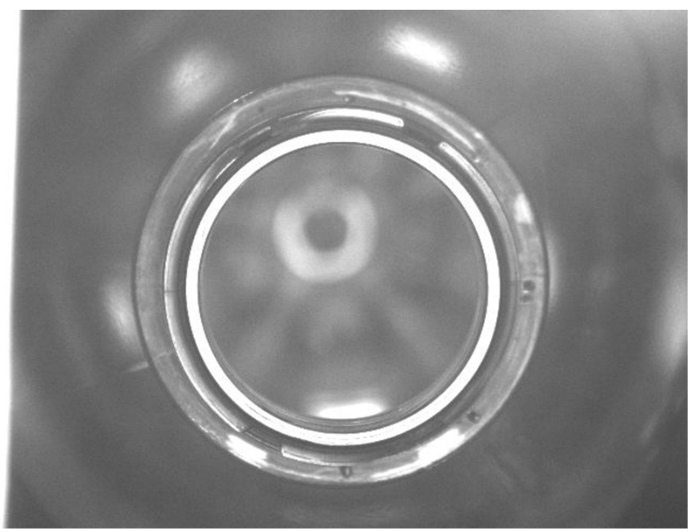
- Surface texture and detail are de-emphasized
- Contrast is de-emphasized
- Useful for curved shiny parts
- Opposite effect of Dark Field

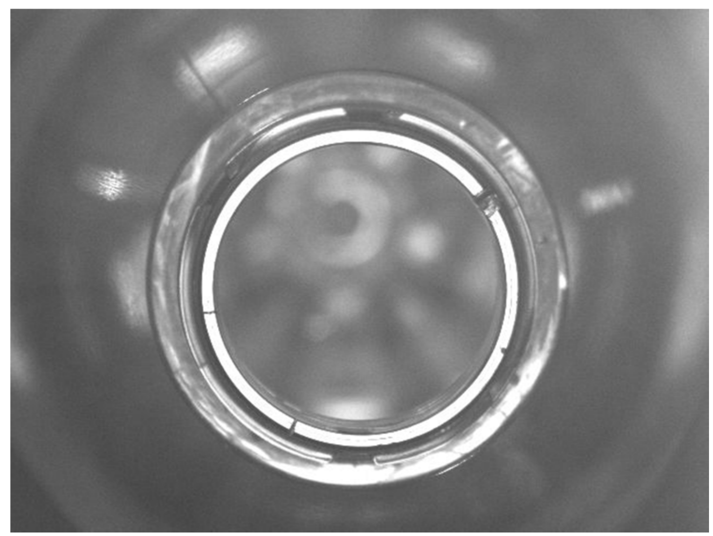


Axial Diffuse Illumination



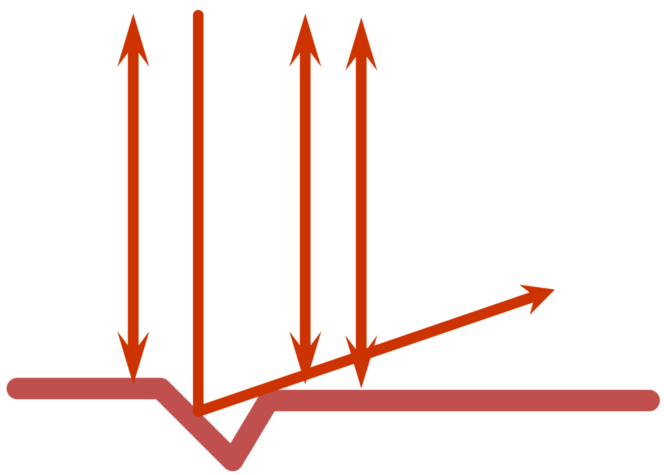
- Light directed at beam splitter
- Used on non-curved, reflective objects





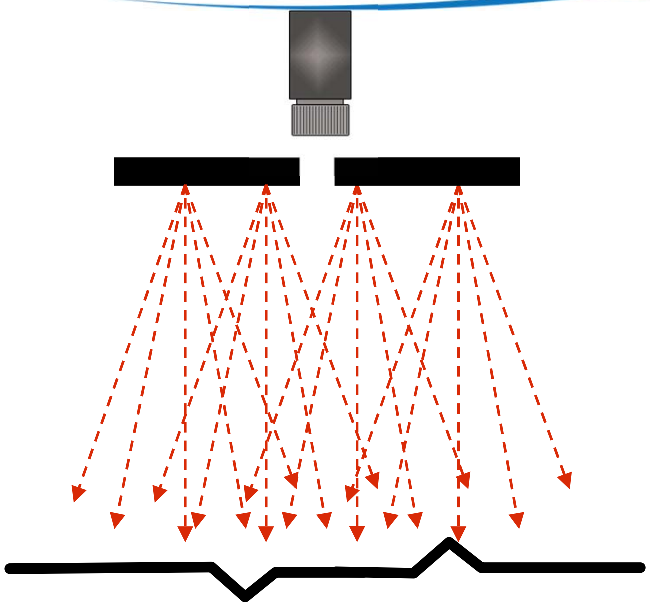
Axial Diffuse Illumination

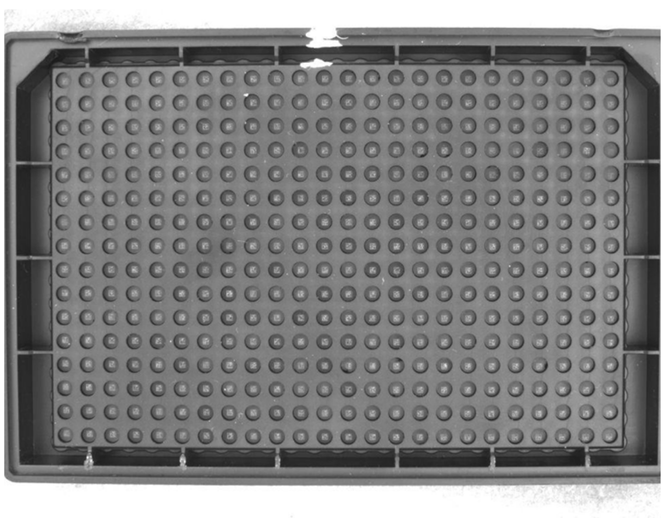
- Surface Texture Is Emphasized
- Angled Elevation Changes Are Darkened

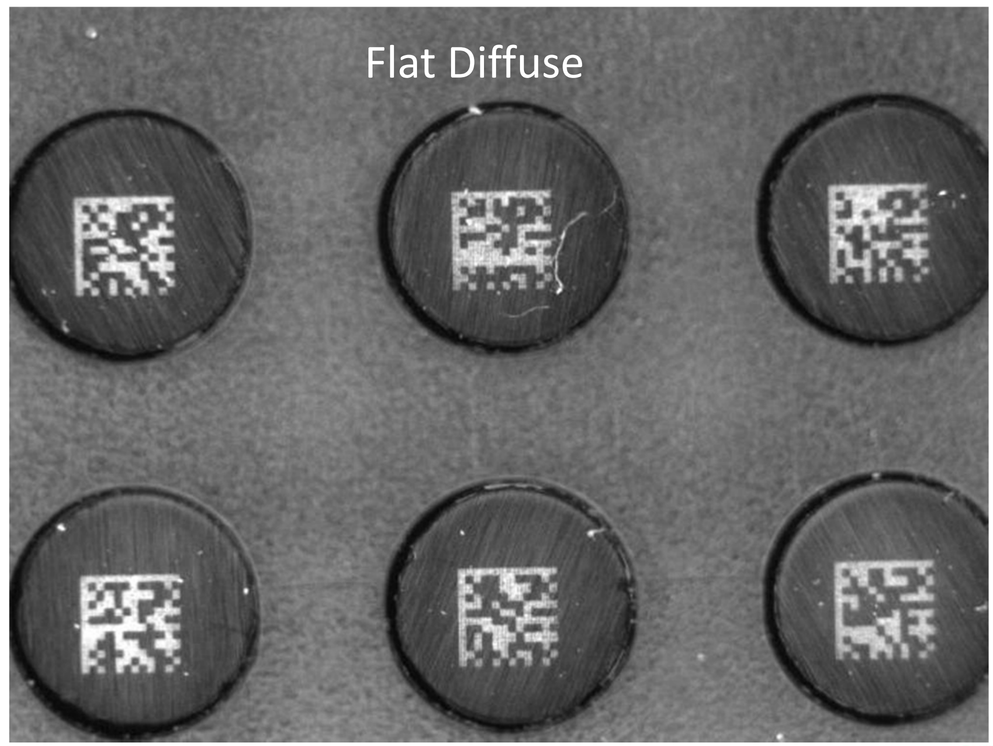


Flat Diffuse

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



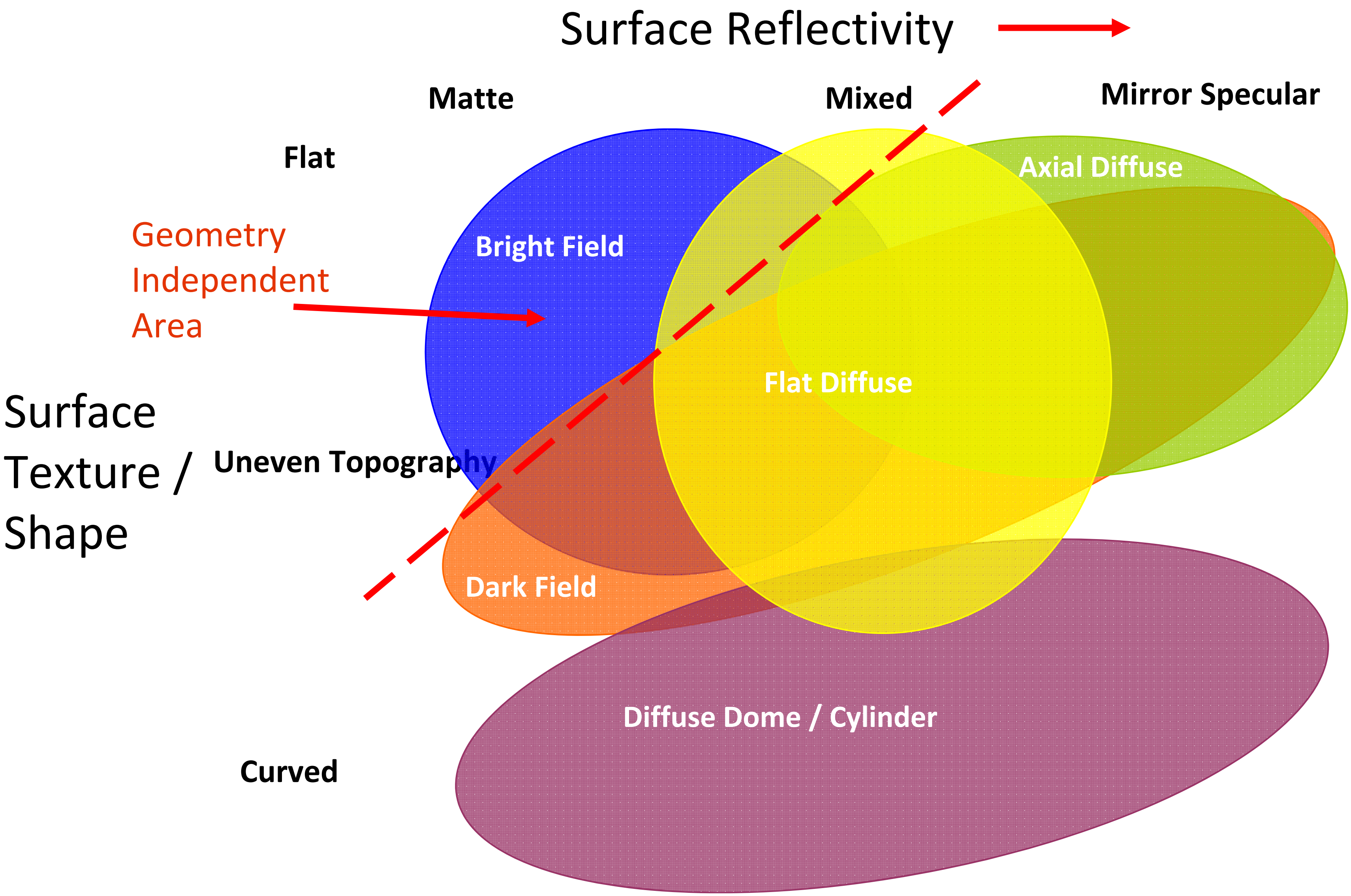




Advantages - Disadvantages

	Partial Bright Field	Dark Field	Diffuse Axial Full Bright Field	Diffuse Dome Full Bright Field
Lighting Type	Ring, Spot, Bar	Angled Ring, Bar	Diffuse Box	Dome Flat Diffuse
When To Use	-Non specular -Area lighting -May be used as a dark field light	-Non Specular -Surface / Topo -Edges -Look thru trans-parent parts	-Non Specular -Flat / Textured -Angled surfaces	-Non Specular -Curved surfaces -If ambient light issues
Require ments	-No WD limit (limited only to intensity need on part)	-Light must be very close to part -Large footprint -Limited spot size -Ambient light may interfere	-Light close to part -Large footprint -Ambient light minor -Beam splitter lowers light to camera	-Light close to part -Large footprint -Camera close to light -Spot size is ½ light inner diameter

Technique vs. Sample Surface



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?

Applications Examples

UPC Bar Code

Printing beneath cellophane wrapped package

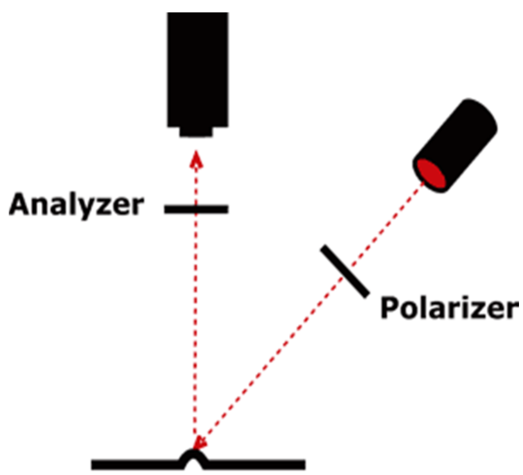
Stamped Date Code

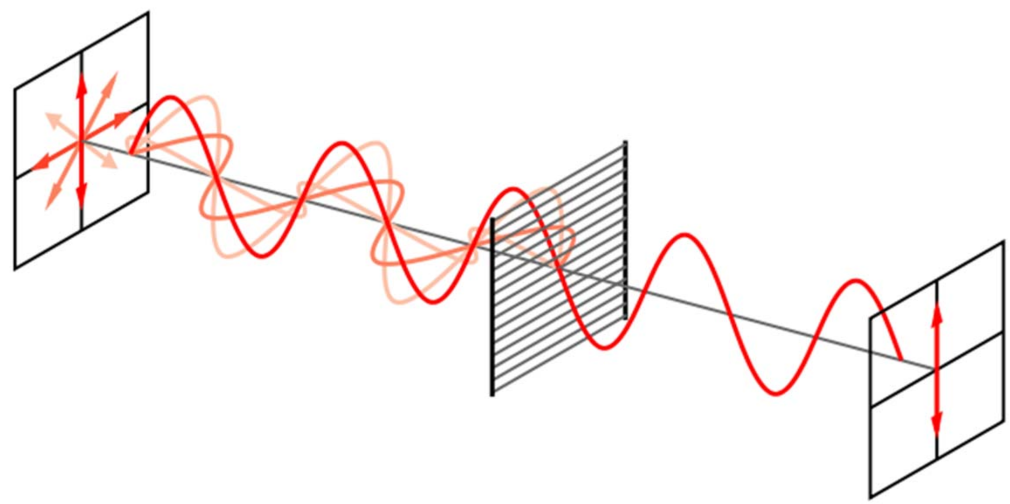
Recessed metal part

Reflective, textured, flat or curved surface

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

Polarizing Filters in Vision

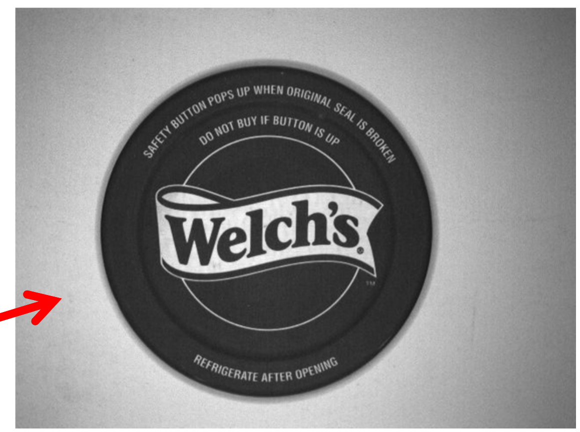
w/o Polarizers

w/ Polarizers

w/o Polarizers

w/o Polarizers

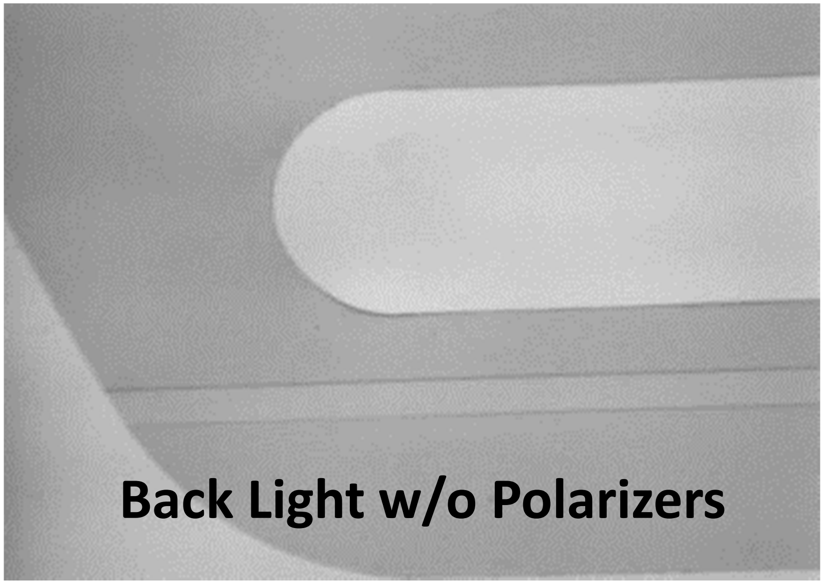
2 ½ f/stops
more open!



w/ Polarizers

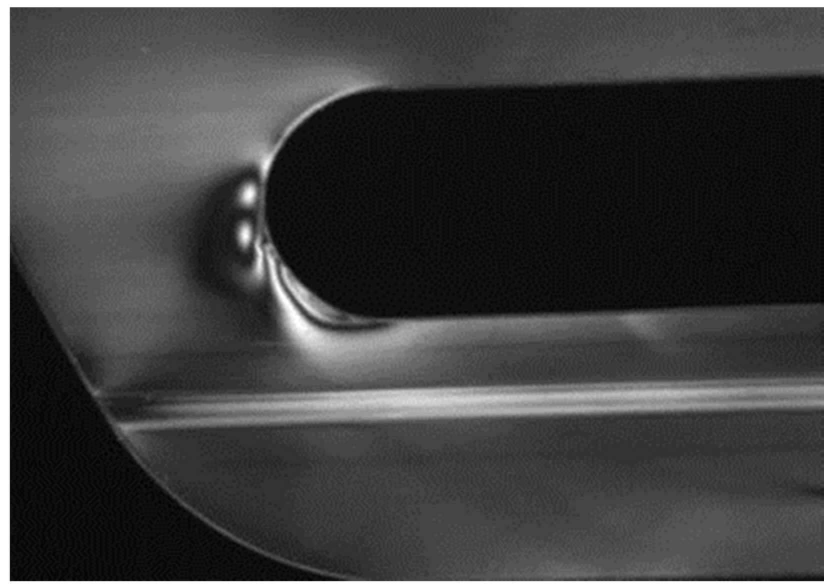
Polarizing Filters in Vision

6-pack Plastic Ring Carrier



Back Light w/o Polarizers

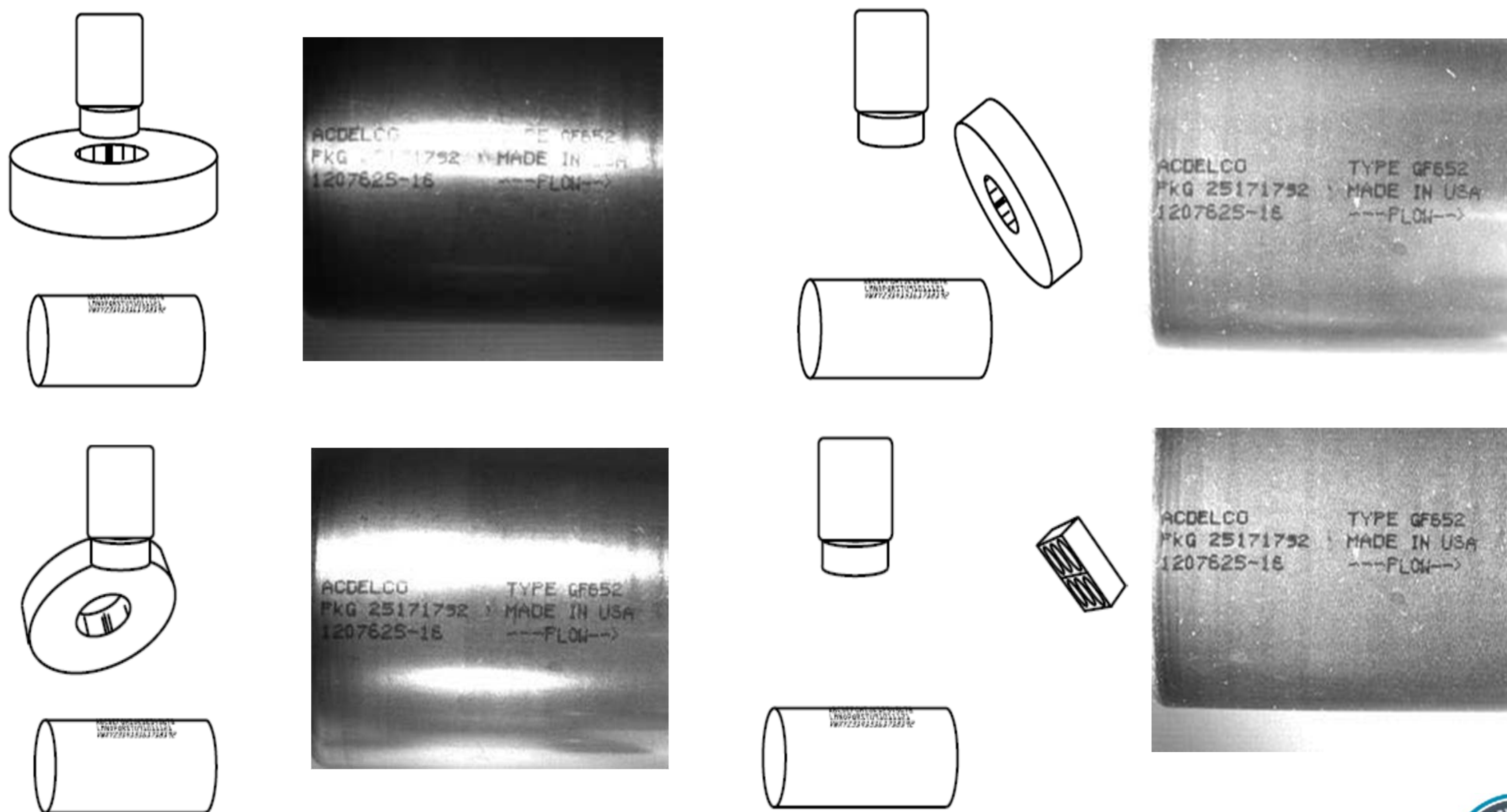
Polarized backlighting is best used to detect internal anisotropy in transparent materials.



Back Light w/ Polarizers

Avoiding Surface Glare

3-D Reflection Geometry: Light - Sample - Camera



Using Color and Wavelength

Create Contrast with Color

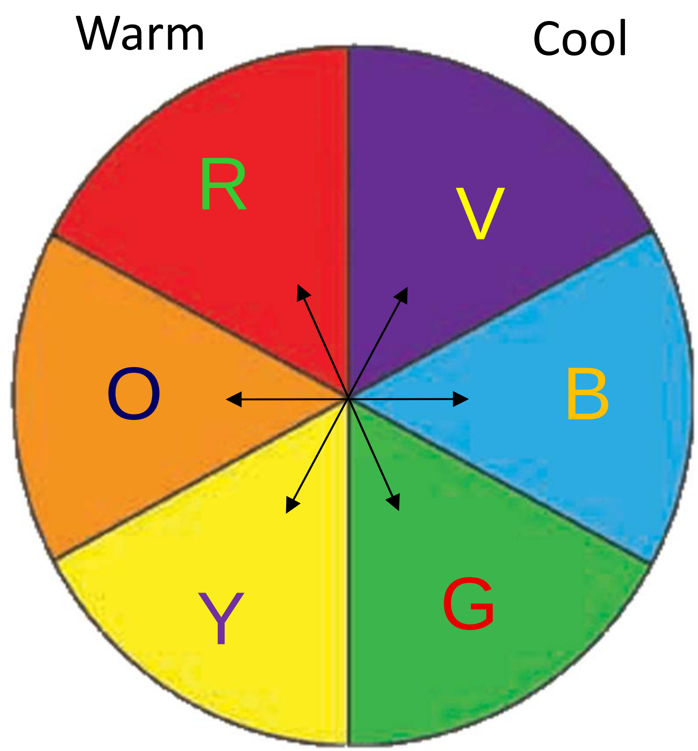
Use Monocolor Light to Create Contrast

Use Like Colors or Families to Lighten

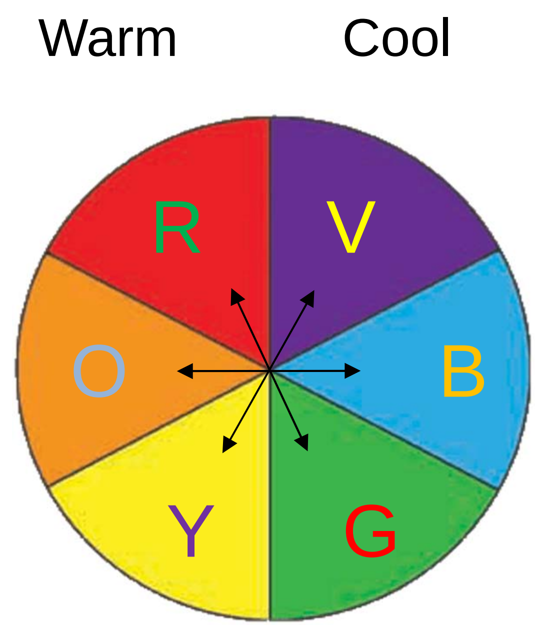
(red light makes red features brighter)

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!

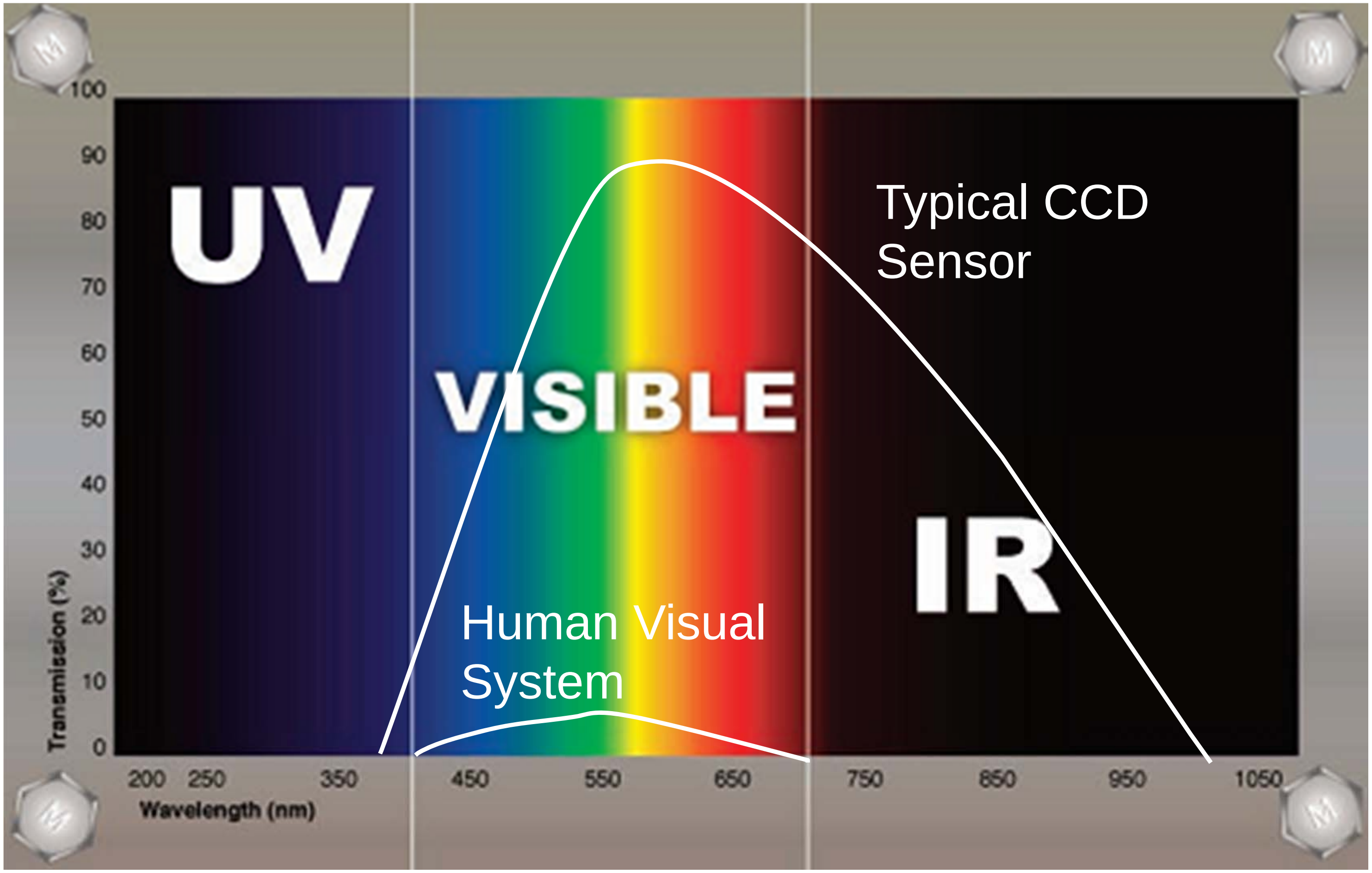
White light will contrast all colors, but may be a compromise.

Wavelength vs. Composition

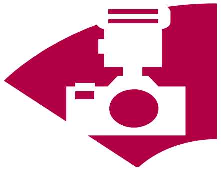
	Monochrome					
	UV	B	G	R	IR	RGB	WHI
Doped w/ UV Fluorescing Agent	X						
Dark Rubber		X					X
Dark Plastics					X		X
Transparent Plastics / Glass				X	X		
Semi-metallic				X	X		X
Metallic		X	X	X	X		X
Mixed Color Parts						X	X
General Purpose				X			X
Ambient Light Problems		X	X	X	X		
Strobe / Ergonomic Issues					X		

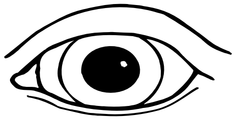
Imaging with Near IR and UV Light

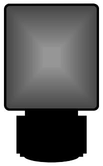
Vision Lighting Spectrum



Graphics courtesy of Midwest Optical, Palatine, IL



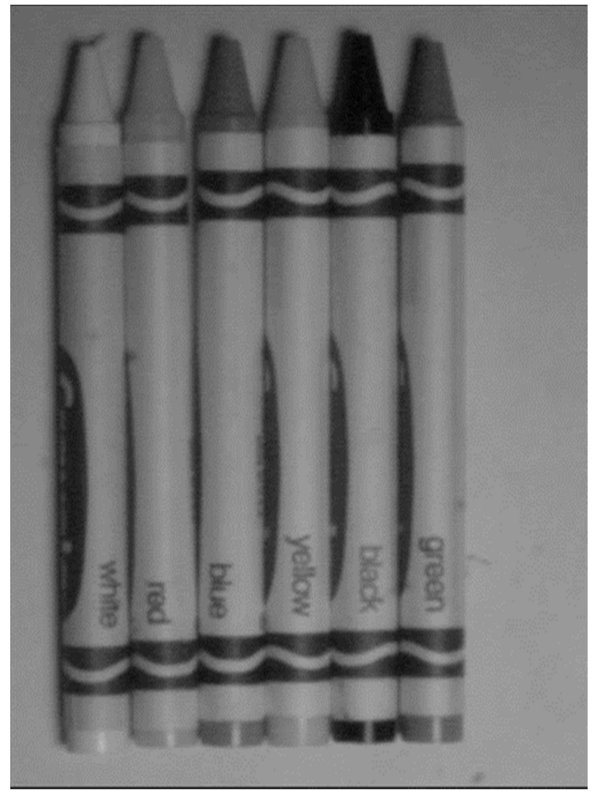




Imaging with Near IR (NIR)

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

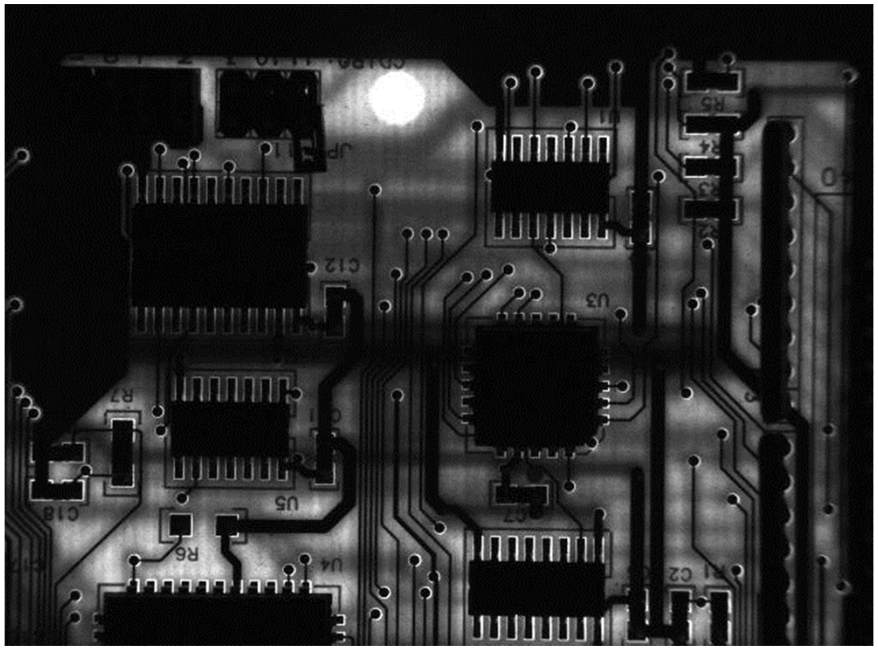
White light – B&W Camera



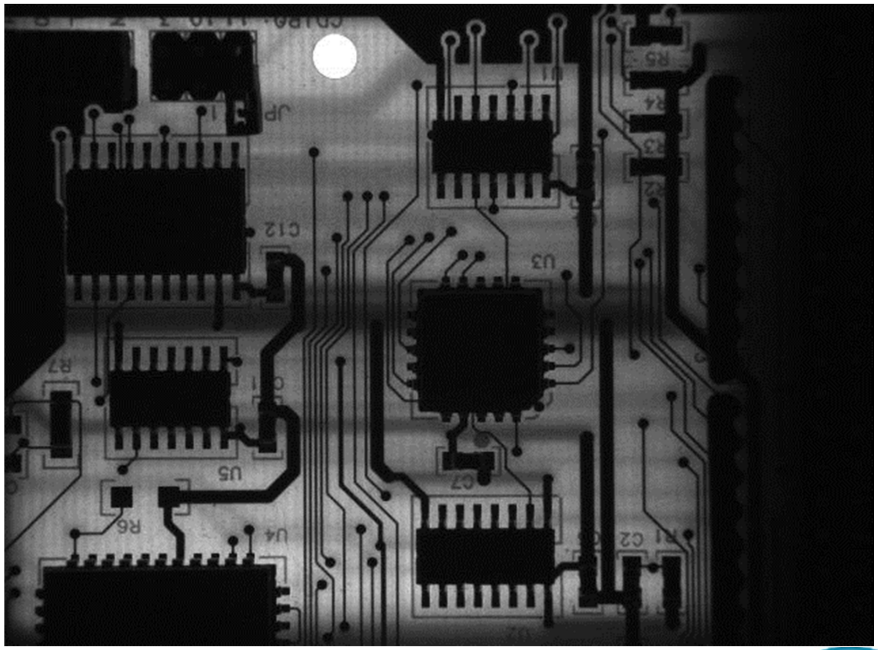
IR light – B&W Camera

Imaging with Near IR (NIR)

- Near IR light can penetrate materials more easily because of the longer wavelength.

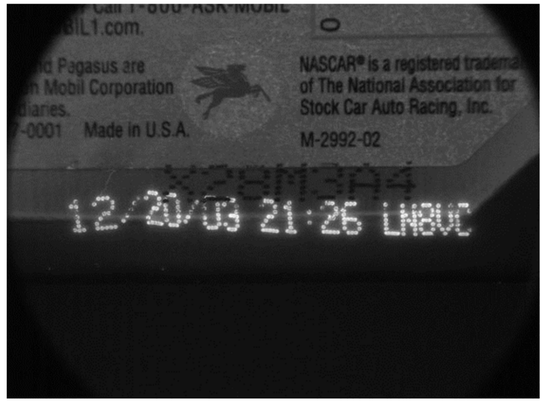


Red 660 nm Back Light

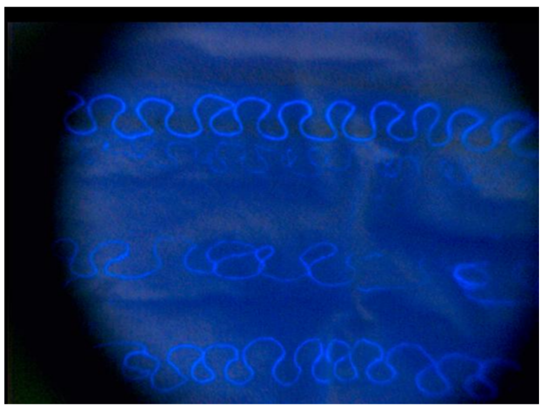


IR 880 nm Back Light

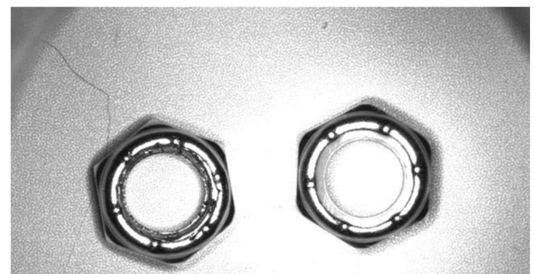
Imaging with UV Light



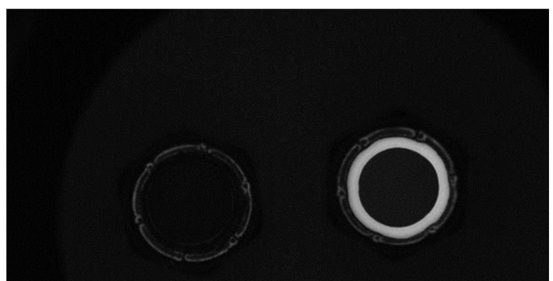
Fluorescing Printing



Fluorescing Polymers (nylon)



Under 355 nm UV and Strong Ambient



Application of a Short Pass Filter

(Briefly) Considering Robotics

VGR Lighting

Robotics with Vision vs. Vision-Guided Robotics

- Yes, there a difference . . .
- Generally, if vision is involved, there’s usually a need for lighting.
- The process for developing sample-appropriate lighting for vision (with or without robotics) is similar. In robotics applications, more emphasis must be placed on?

The 3-D Working Volume

around your Sample!

VGR Lighting

Working Volume = 3-D Relationship among:

Sample + Camera + Light + Robot(s)

Scenarios: (Just for a typical Coaxial* Ring Light application)

- Camera/Light in Fixed Position - Robot Moves (most inflexible)
- Camera/Light Not in Fixed Position - Robot Moves
- Camera on Robot, Light in Fixed Position & vice-versa
- Camera & Light on Robot in Coaxial Position (most flexible)
- Camera & Light on Robot; Light in Off-axis (non-coaxial) Position

* Coaxial geometry implies ring light surrounding lens

VGR Lighting

General Lighting Modes – Robotics

- Large Area/FOV – Often Indirect Ceiling Lighting
  Usually large Industrial Robots, heavy sample transfers or picking smaller parts from dunnage; often relies on long WD, diffuse fluorescent or mercury plant lighting.
- Medium Area Enclosed Work Cell – Indirect ceiling or dedicated work cell lighting, typically fluorescent or LED-based.
- Any Size Semi-enclosed or Enclosed area with the Camera and/or Lighting attached to the Robot. This style allows for the most lighting flexibility – DoF for Robotic Movement.

VGR Lighting - Examples

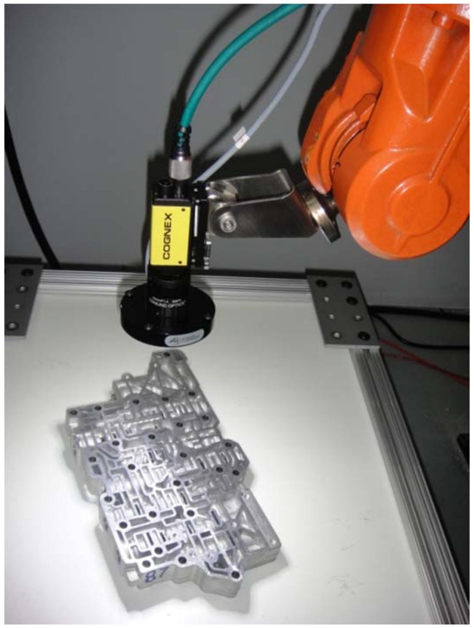
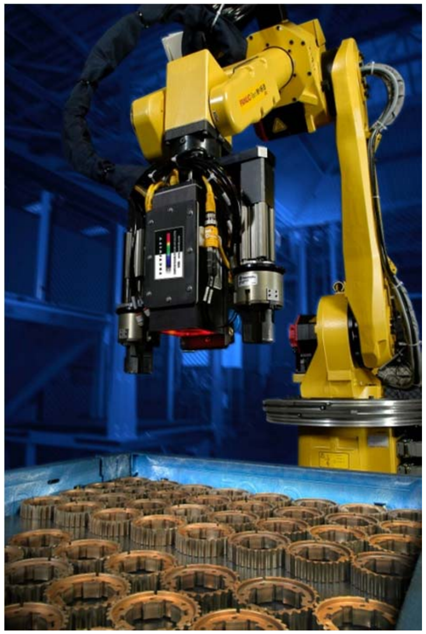


Image courtesy of Cognex Corporation, Natick, MA



Images Courtesy of Tectivity Inc., Milford, MI

VGR Lighting

Asking the same questions:

- What objects?
- What features are important?
- What lighting type/technique is sample/feature-appropriate?
- What are my Field-of-View (FOV) and Working Distance (WD) ranges and restrictions?

+

- Interaction with Robot(s) and sample dunnage, conveyance? (Multiple DoF Movements)

Review and Summary

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

- Coordinated Lighting and Lensing are crucial
- Develop the lighting solution early on in the vision system development process
- Start lighting development on the bench if necessary
- Consider the 4 cornerstones for enhancing contrast
- Be aware of and block ambient light
- Maintain Control of the Lighting Environment
- Remember that light MAY interact differently w/ respect to surface texture, color, composition and wavelength
- Make the lighting solution robust
- Need more help? – Call your lighting professional . . .

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