(Artificial) lighting for image analysis

Václav Hlaváč

Czech Technical University in Prague

Czech Institute of Informatics, Robotics and Cybernetics

160 00 Prague 6, Jugoslávských partyzánů 3, Czech Republic

http://people.ciirc.cvut.cz/hlavac, vaclav.hlavac@cvut.cz

also Center for Machine Perception, http://cmp.felk.cvut.cz

Courtesy: Vladimír Smutný, lectures of others.

Prerequisite: Image formation lecture.

Outline of the talk:

- Polarized light
- Illuminants, taxonomy.
- Use of (photo)filters.
- Special illumination arrangements.

Why do we use artificial lighting for machine vision?

We need to control of the lighting environment:

- to create a proper and consistent environment for a given (industrial inspection) task.
- to solve the given task, to standardize techniques, components, and implementations.
- to achieve reproducibility of inspection results and variability to most variations.

Creating the contrast is the most important.

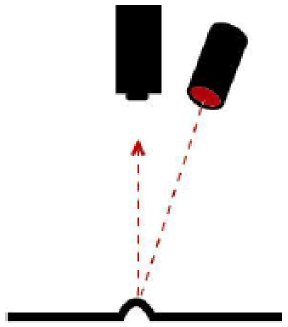
- Features of interest (signal) should have maximum contrast.
- Features of no interest (background, noise) should have minimal contrast.
- We want the minimal sensitivity (robustness) to normal variations as minor part differences, presence or change of ambient lighting.

How do we change/maximize contrast?

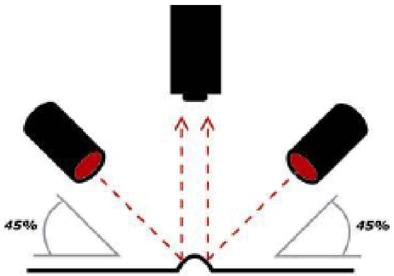
- Change light / sample / camera geometry: 3D spatial relationship between the sample, light source and camera.
- Change Light Pattern (structure): Light head type (spot, line, dome, array); Illumination type (bright field, dark field, diffuse, back lighting).
- Change spectrum (color / wavelength): Monochorme / white vs. sample and camera response; Warm vs. cool color (object vs. background).
- Change light character (filtering): Affecting the wavelength / direction of light to the camera.

We need to understand the impact of incident light on both the part of interest and its immediate background!

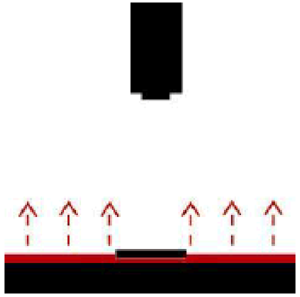
Common illumination techniques



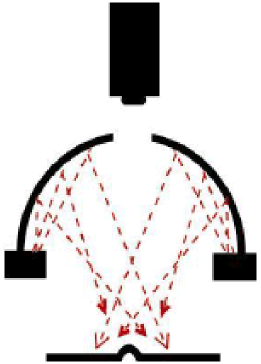
Full/Partial Bright Field



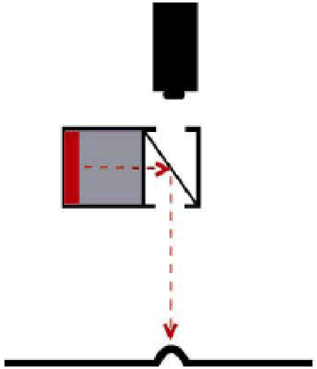
Dark Field



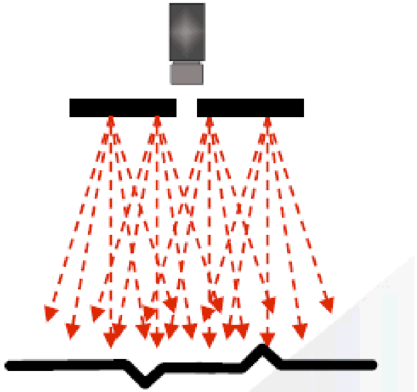
Back Lighting



Diffuse Dome



Axial Diffuse



Flat Diffuse

Illuminants according to the emission (1)

Day light – no flickering, unstable in time and color, very good viewing colors.

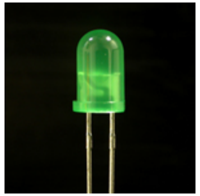
Incandescent lamp – does not flicker, warms the device, big energy input, big starting current, should be changed often, good for viewing colors.

Halide lamp – no flickering, should be changed often, good for viewing colors (better than incadescent lamp), smaller than incadescent lamp.

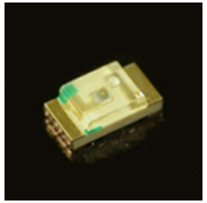
Fluorescent lamp – flickering (it is possible to power it with high frequency current or synchronize it), needs special power source, long life, bad for viewing colors, close to surface source (in Czech plošný zdroj).

Illuminants according to the emission (2)

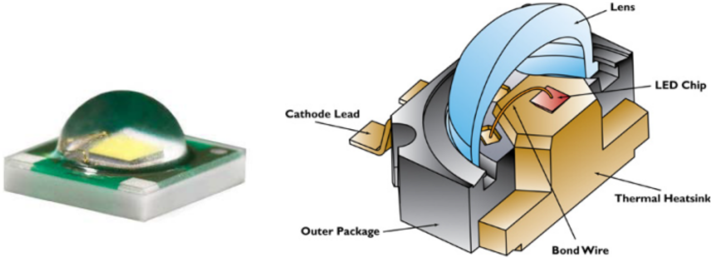
LED – Light Emitting Diode, modulated light, no warming, small size, low power consumption, monochromatic (also infrared, white color), long life.



standard



surface mounted

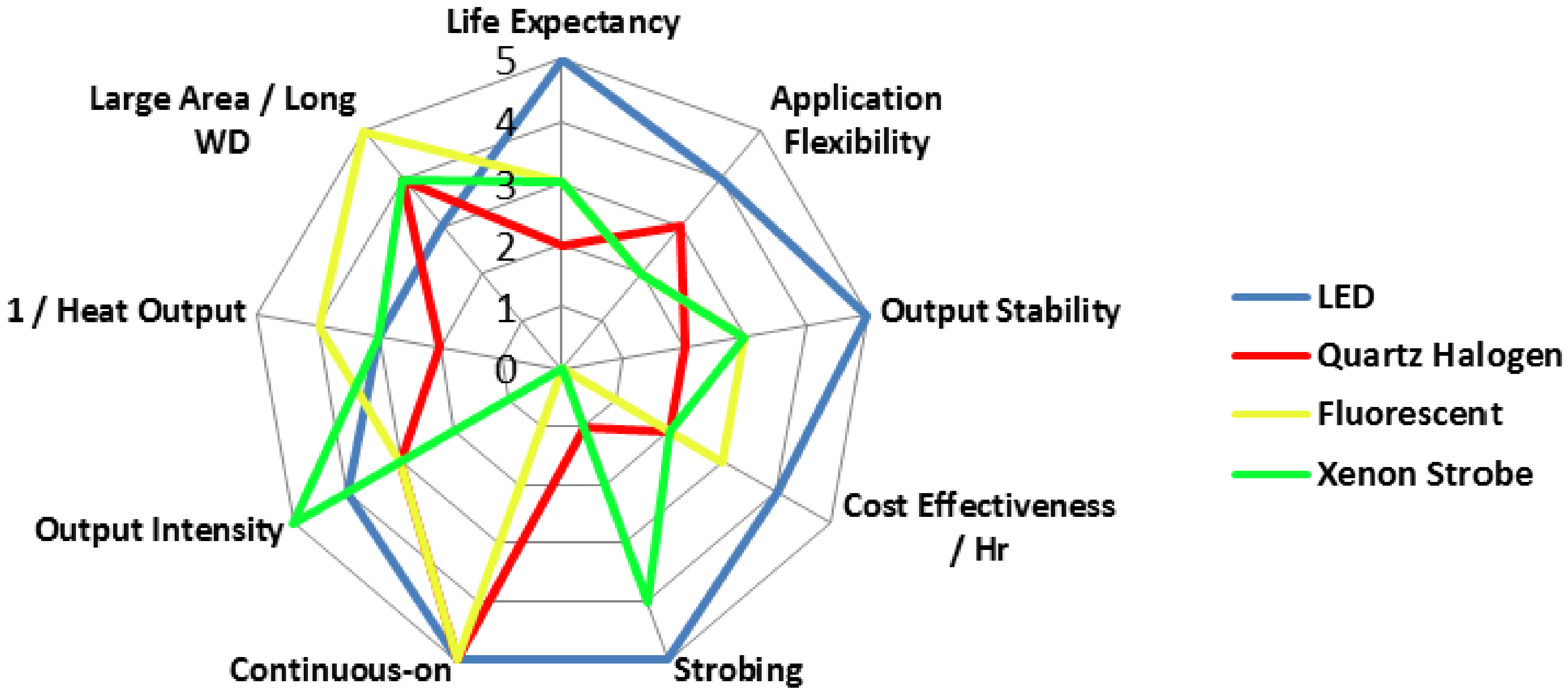


high current LED

Laser – Light Amplification by Stimulated Emission of Radiation). Device producing light of a single (pure) color = monochromatic. Can be modulated, coherent (=same phase) $\Rightarrow$ problems with interferences, low power consumption, long life for semiconductor lasers.

Flash tubes – e.g. xenon lamps, used in applications in which big power is needed, very expensive.

Properties of common primary vision light sources



Illuminants according to the size (1)

Point sources – E.g., halid lamp, LED, laser. Emphasize the roughness of the surface. Strong highlights.

Surface sources, diffuse source – E.g., reflection from a white opaque wall, paper, fluorescent lamp, illuminants with large focusing screen (in Czech matnice). Suppresses the roughness of the surface..

Back light diffuse – It is of advantage in the cases, in which only the silhouette of the object is of interest and the object is thin (as metal sheet, animal skin, . . .). It is Very used in applications very often as it simplifies segmentation to objects and background significantly. Suitable for gauging (in Czech měření rozměrů).

Illuminants according to the size (2)

Blacklight, telecentric – illuminants with collimators. It can be used only for small objects (up to diameter of the lens aperture). It is often combined with telecentric lenses. It is suitable in the cases, in which silhouette of thin objects is of interest.

Dark field – oblique illumination when rays are not directed to the lens, there is a reflection from object to the lens.

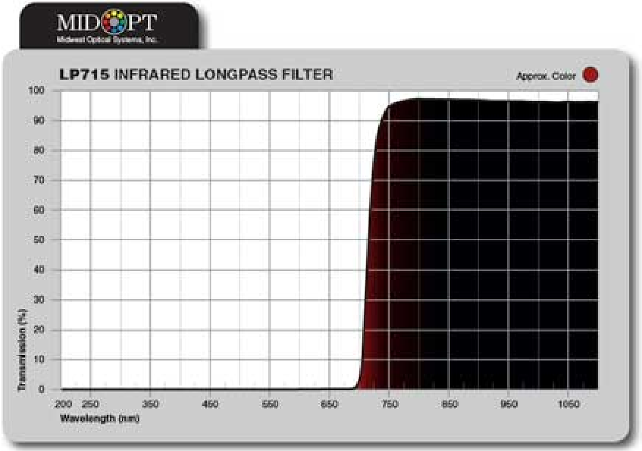
Optical filters may help

Monochromatic filter can suppress an ambient light and decrease the influence of color abberations.

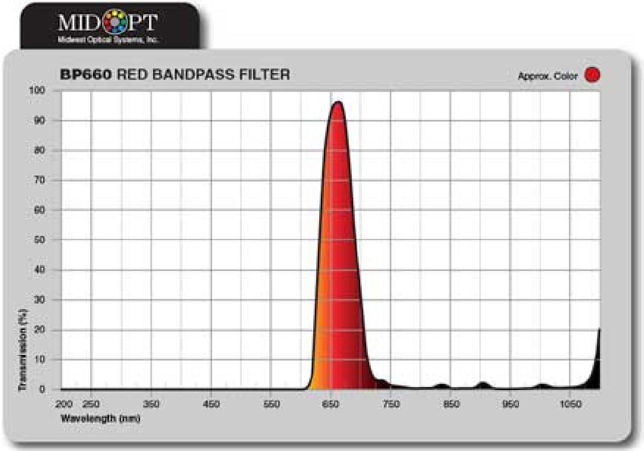
Polarized filter removes or enhances a polarized image, e.g., reflection from a glass cover of the device. We will explain it in this lecture later.

Optical filters in machine vision

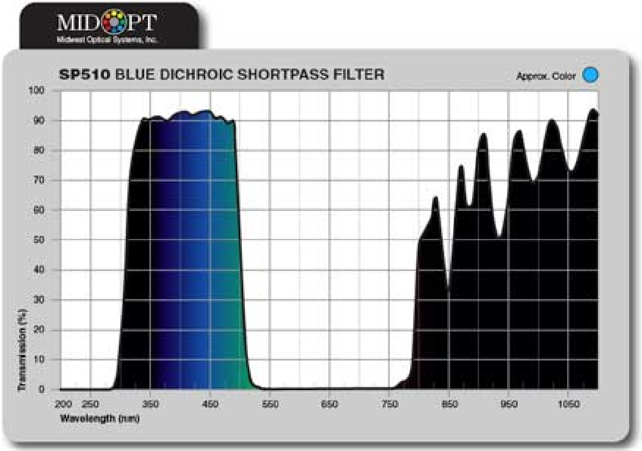
- Here we deal with optical filters exclude certain part of light spectrum.
- A filter can suppress the sunlight or mercury vapor light source intensity approximately four times.
- A filter can suppress the fluorescent light up to approximately 35 times.



715 nm long pass



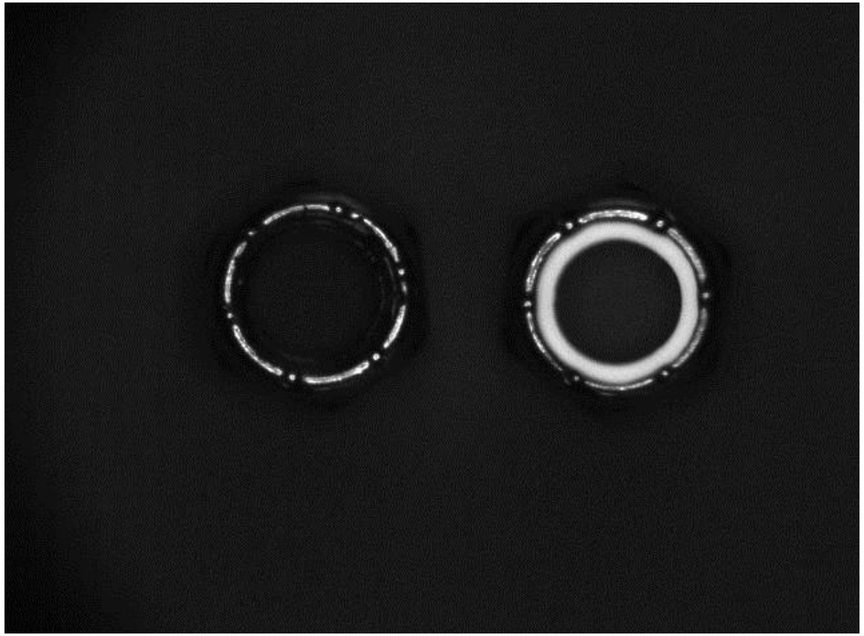
660 nm band pass



510 mm short pass

Example, imaging with near UV illumination

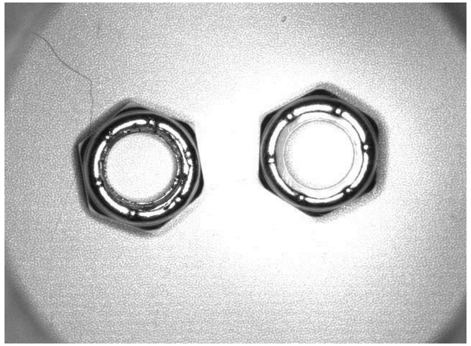
Near UV light fluoresces many polymers, including nylon.



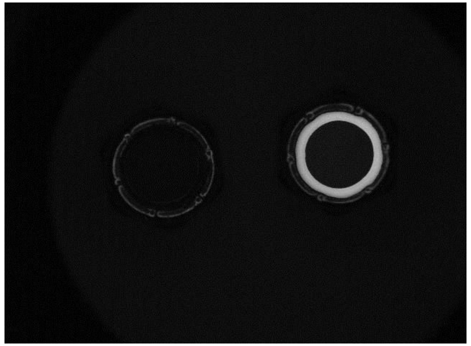
Use of optical filter, example

- Visualizing a plastic ring, the polymer-insert lock nut

- UV light with a strong red 660 nm ambient light

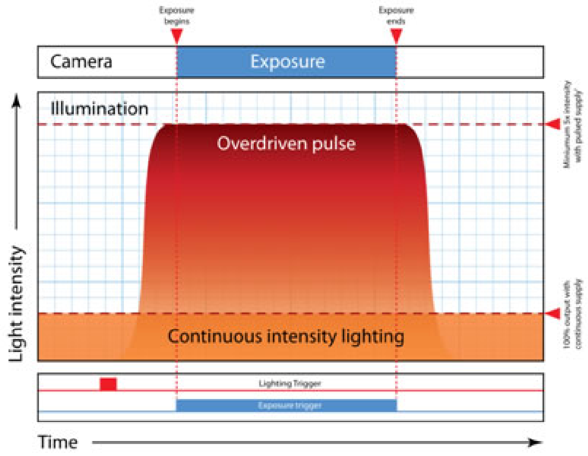


- Same UV and ambient light with 510 nm short pass filter applied



Suppressing undesireable ambient light

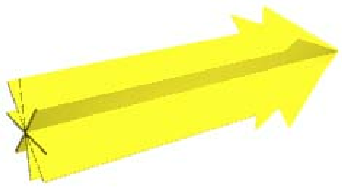
- Ambient light is any light other than the vision-specific lighting that the camera collects.
- Controlling and negating ambient light:
  - Turn off the ambient contribution – *Most effective, least likely!*
  - Build a shroud – *Very effective, but time-consuming, bulky and expensive*.
  - Overwhelm the ambient contribution with a high-power lighting (continuous-on or strobe overdrive) – *Effective, but requires more cost and complexity*.



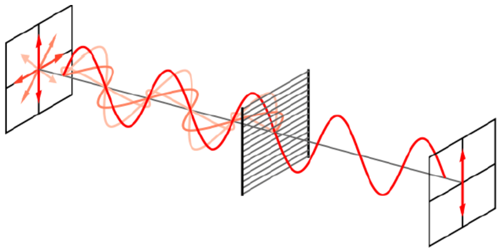
  - Control it with pass filters – *Very effective, but requires a narrow-band source light*.

Light polarization (1)

- Radiance is expressed as an oscillating electrical and magnetic field in the theory of electromagnetic field.
- Vector fields describing the intensity of the electric field E and the intensity of magnetic field B are solution to the system of Maxwell's linear differential equations.
- The direction of vector E in 3D varies in general. E.g., the Sun (due to short emission phenomena) or incandescent lamps provide mainly a random mixture of waves containing all E orientations, so called unpolarized light.



- A polarization filter (polarizer) selects waves lying in a single plane, so called linearly polarized light.



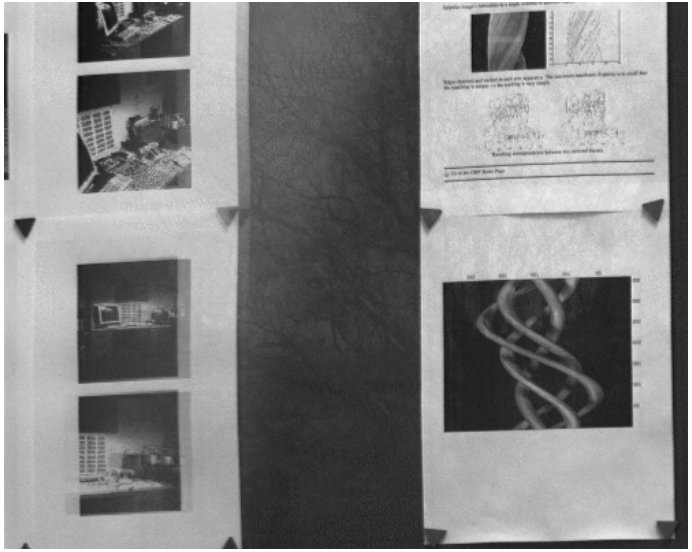
Light polarization (2)

- A *harmonic planar wave* is a solution to Maxwell's differential equations in a free space (not taking into account electric potentials and currents).
- The unpolarized light, coming e.g. from Sun, is polarized after passing through a polarizing filter.
- Nature provides a polarization filter in, e.g. Iceland spar (in Czech: dvojlomný vápenec). Artificial polarization filters consists of parallel fibres of elongated molecules oriented in one direction.
- Examples: Polarized spectacles for fishermen. Polarized filter for a camera lens.

Influence of a polarized filter, the example

There is a clear glass positioned vertically in front of a camera and it is tilted with respect to the camera optical axis by about 45°. A double refraction on the glass is visible in both images.

Vertical polarization.
Window reflected in a glass.



Horizontal polarization.
Reflection suppressed. Visibility through.

Influence of a polarized filter, the example (2)

On-axis Light w/o Polarizers

Off-axis Light w/o Polarizers

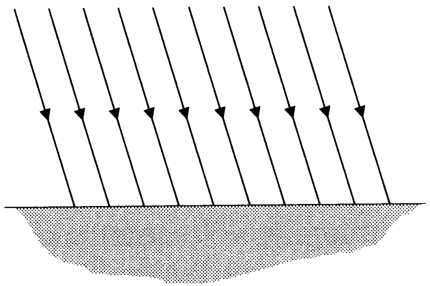
On-axis Light w/ Polarizers

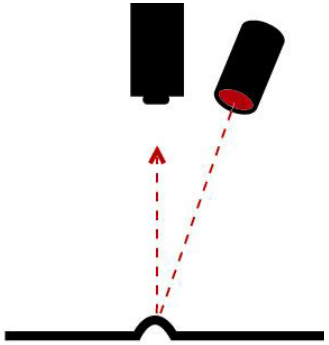
w/o Polarizers

2 ½ f/stops more open!

w/ Polarizers

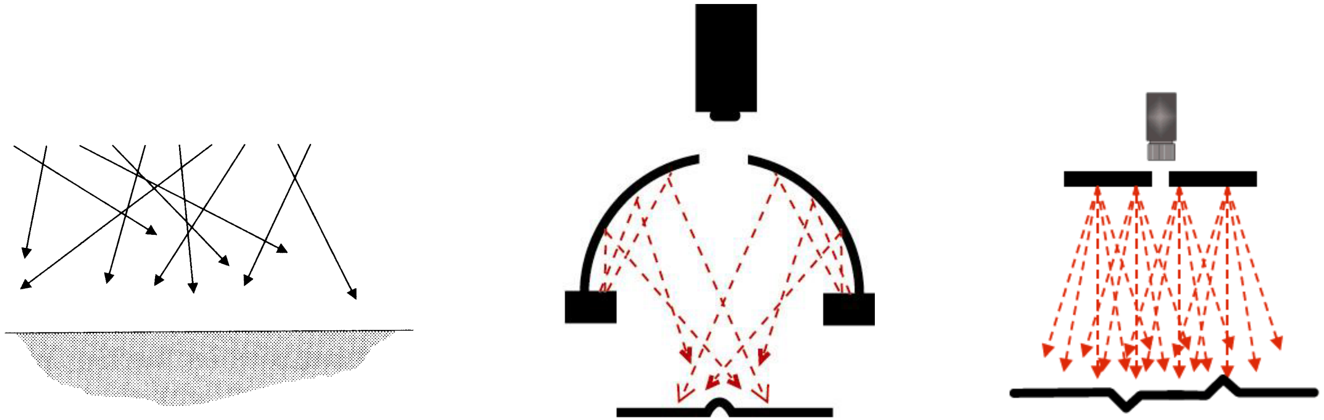
Partial bright field (also directional or ring) illumination





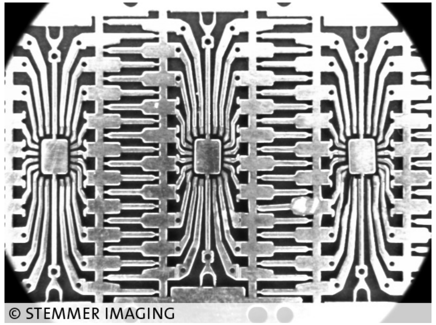
- Irradiance of the opaque surface (ideal case: Lambertian) depends on the surface direction. That is the reason why the tilt of the surface can be measured (shape from shading). One of the first applications was in measuring shape of planetary surfaces, e.g. Venus craters.
- Shadows can generate edges in images, which can be confused with object boundaries.
- The mirror component of reflectance causes highlights. If this the problem then directional illumination is not suitable. Try dark field.

Full bright field (also diffused) illumination

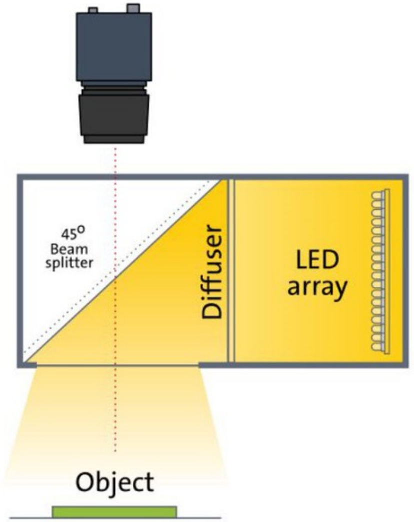


- Natural day light with overcast sky, fog.
- Solution in devices: circle from LEDs, semi-sphere from LEDs.
- Useful for surfaces with significant mirror component of reflectivity.

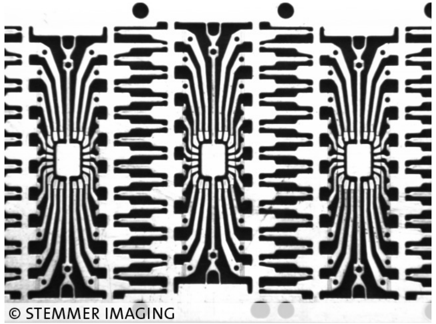
Coaxial illumination



ring bright field
uneven light in the center



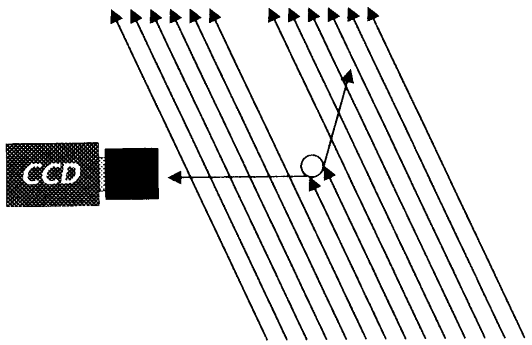
coaxial illumination

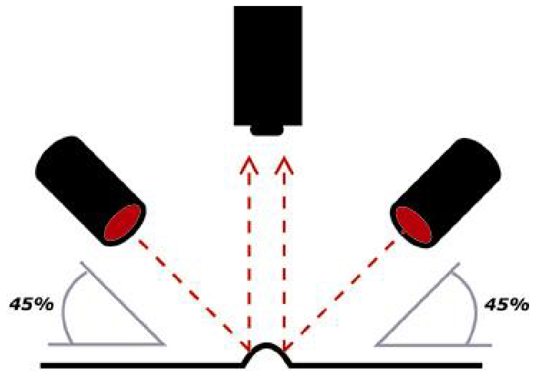


even light
in the center

It is used for illuminating reflective surfaces. It is suited for plain reflective, 'mirror-like' objects with no (or very little) profile or any surfaces which have diffuse backgrounds. Examples include PCB inspection, reflective labels, polished silicon wafers or print inspection.

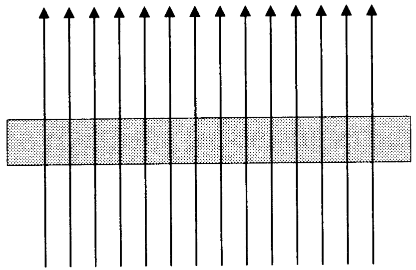
Dark field illumination

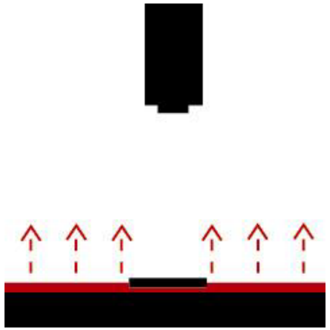




- Rays from the illuminant are not directed to the camera.
- Refraction, reflection, diffusion of light which falls to the camera is visible. Objects are light on the dark background..
- Used to visualize small particles, metallic surfaces in microscopy (e.g., aluminium conductors in microelectronics).

Backlight illumination





- Useful when the silhouette of the non-transparent object is sought. Simplifies segmentation.
- Useful also for semi-transparent objects where a range of interactions between light and matter can be observed (refraction, absoption, diffusion of light). Local inhomogeneities in the matter can be detected.
- Examples: X-ray. Spectral analysis when absorption depends on frequency.

Backlight diffuse; example – a liquid level in a bottle

It is not easy to check the fill level of a brown bottle under normal domestic lighting.

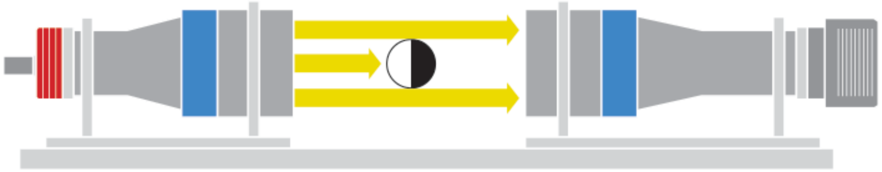
Bottle captured using a high intensity backlight to create a clear image of the liquid surface.

Backlight diffuse vs. collimated; plastic bottleneck example

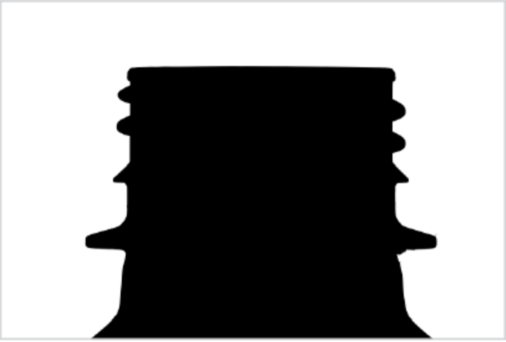
Non-collimated back illumination

Light coming from a variety of angles

Collimated back illumination

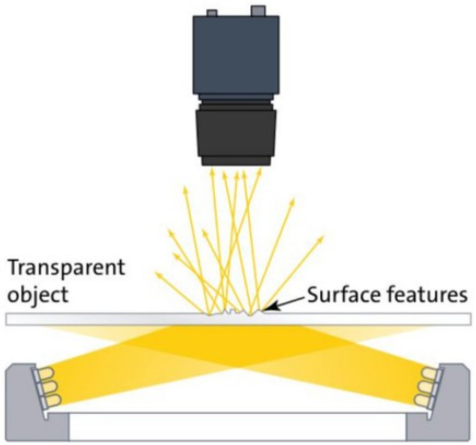


Parallel rays

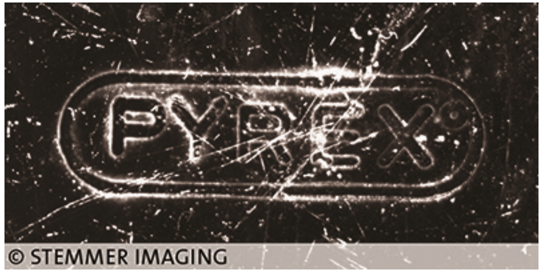


Dark field backlight illumination

- Uses a dark field light behind a transparent object (e.g., glass, plastic] to reveal surface features.
- It is good for defects such as scratches, or to check the quality of embossed or raised lettering.



ordinary backlight



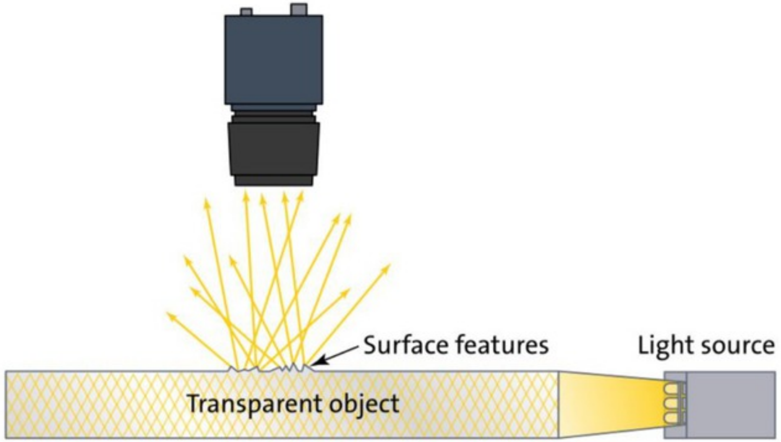
dark field backlight

lens with small depth of field removes scratches

Dark field backlighting using transmissive illumination

Light is only reflected when the surface of the transparent material is scratched, cracked or in some other way deformed.

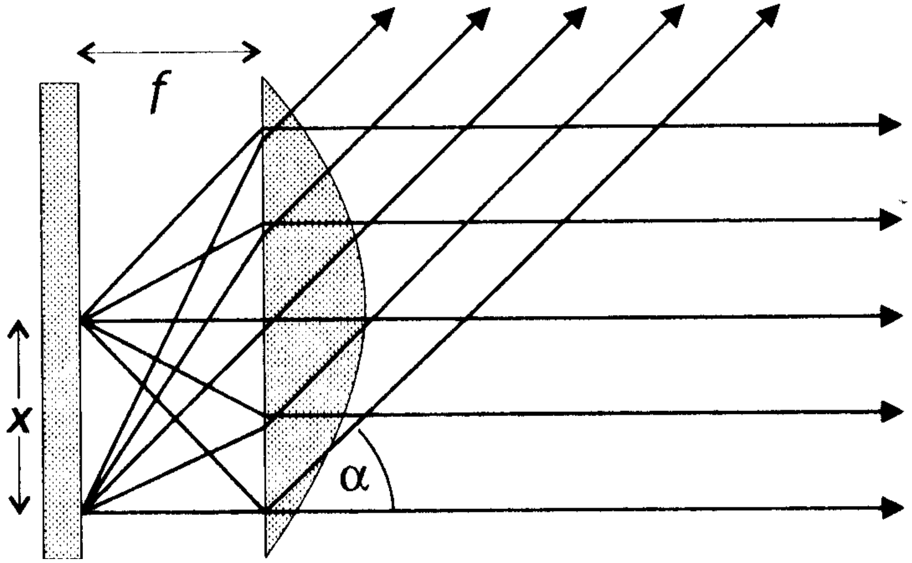
standard coaxial illumination



light is injected into the transparent material

dark field backlight

Telecentric illumination



- A collimator secures parallel rays.
- Lenses of big parameters have to be used if objects are large (often Fresnel lenses = steps-like lens from concentric elements).
- The measured gauge is invariant to the distance of the object from the lens.