Image Acquisition

Lighting & Digitalization

Technical University of Applied Sciences Würzburg-Schweinfurt

Lighting

- Requirements
- Radiometric quantities
- Spotlight source
- Types of illumination

Digitalization

- Photoelectronic image acquisition
- Color images
- Different types of camera systems

Light sources & Object properties

In order to interpret images and reconstruct 3D scenes, it is necessary to understand all factors of the image capture. This includes not only the geometry of projection but also the lighting of a scene. This happens by reflection, refraction and scattering of light.

- Both the object properties,
- as well as the type and position(s) of the light source(s)

play an important role. The solution to an image processing problem depends largely on, whether

- the lighting conditions are given unchangeable,
- or can be optimally set up.

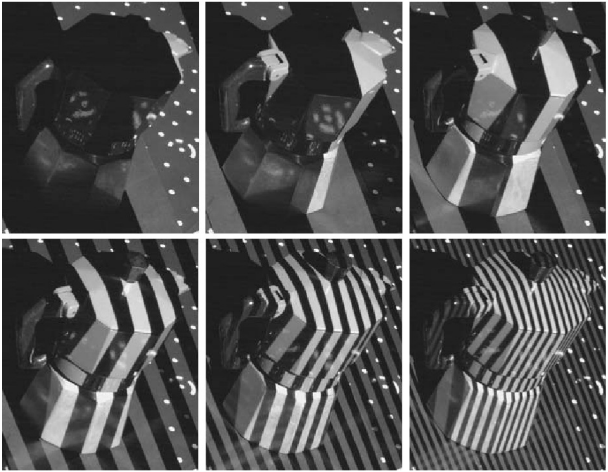
If the lighting conditions can be influenced, a good match of lighting and evaluation technique helps to improve the quality of the result decisively.

unchangeable

optimized

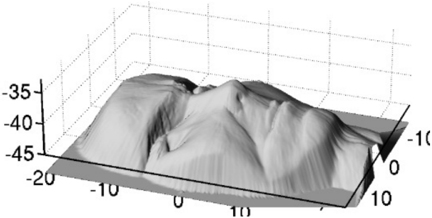
Lighting

Application example - Structured Light



Lighting

Application example - Shape from Shading



- position of the light source known
- assumption of a Lambertian surface (uniform diffuse reflection)
- profile from irradiance

Lighting

Requirements and Design

lighting objective: Produce homogeneous lighting conditions and create an optimal light/dark contrast.

requirements

- constancy of illumination in wavelength and intensity
- certain color compositions (wavelength ranges)
- certain shaping (ring field, long field)
- no flickering, low heating

interpretation

- Matching wavelength ranges of light generation to the sensitivity of the sensor.
- Matching of wavelength ranges and the illumination type to the reflection and absorption properties of the objects

Lighting

Radiation Physics - Lighting Technology

- Radiation physics (radiometry): Describes the objectively emitted radiation.
- Light technology (photometry): Describes the radiation subjectively perceived by humans. It takes into account the wavelength dependency of the sensitivity of the human eye.

Radiometric quantities	**SI-units**	**Description**
Radiation energy	$[J]$	The energy of a number of photons
Radiation flux	$[W]$	Radiation energy per time
Radiation intensity	$\left[W/sr\right]$	Radiation flux per solid angle
Irradiance	$\left[W/m^2\right]$	Radiation flux per effective receiver area

Photometric quantities	**SI-units**	**Description**
Light quantity	LumenSecond $[lms]$	The energy of a light source
Luminous flux[1]	Lumen $[lm]$	Radiant power weighted by $V(\lambda)$
Luminous intensity[2]	candela $[cd]$	luminous flux per solid angle
illuminance[3]	lux $[lx]$	luminous flux per area

[1] $V(\lambda)$ = brightness sensitivity curve: describes the spectral brightness sensitivity of test subjects in daylight.

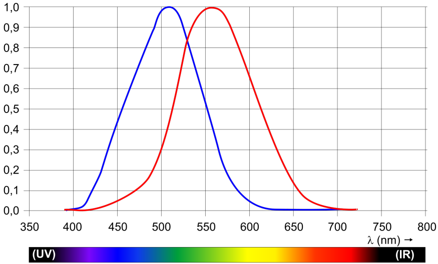
[2] Indicates how intense a light source shines in a certain direction.

[3] Indicates how brightly an area is illuminated.

Lighting

Brightness sensitivity curve

Describes the spectral brightness sensitivity level of test subjects in daylight (red) and at night (blue).



Lighting

Radiometric quantities

Radiation energy: Sum of the energies of all photons involved.

$$Q = \int_0^\infty n_\lambda e_\lambda d\lambda\,, \quad \text{with } e_\lambda = \frac{hc}{\lambda} \quad \text{energy of a photon}\,.$$

Radiation flux: Energy emitted by a light source per time.

$$\Phi = \frac{dQ}{dt}\,.$$

Radiation intensity: Radiation flux emitted by a light source at a given solid angle.

$$I = \frac{d\Phi}{d\omega}\,.$$

Lighting

Radiometric quantities

Irradiance: Power received at a point x from all directions

$$E(x) = \frac{d\Phi}{dA}\,, \quad \text{where } A \text{ is the irradiated area}\,.$$

Solid angle: Is the area S of a section of a sphere surface per square sphere radius r^2

$$\omega = \frac{S}{r^2}\,, \quad d\omega = \frac{dA\cos\theta}{r^2}\,, \quad \omega = 4\pi \text{ (sphere surface)}\,,$$

where θ is the angle of incidence of the radiation on the surface A.

Point light source - Model

The simplest model of a light source, is the point light source. Any arbitrarily shaped light source can be modeled by spatially composed point light sources. The radiation pattern of a light source results from integration of the radiations of the individual point light sources.

An isotropically radiating point light source radiates uniformly in all directions with a total radiation flux of

$$d\Phi = I d\omega \,, \quad \text{for } I = const. \rightarrow \Phi = I \int d\omega = I 4\pi \,.$$

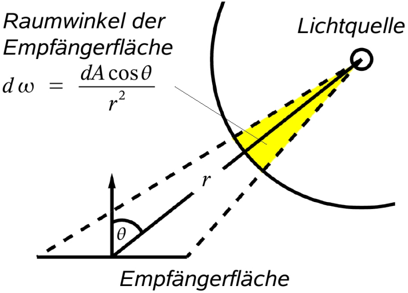
Thus, the irradiance from a point source is given by

$$E(x) = \frac{d\Phi}{dA} = \frac{I d\omega}{dA} = \frac{\Phi}{4\pi} \frac{dA \cos\theta}{r^2} \frac{1}{dA} = \frac{\Phi \cos\theta}{4\pi r^2} \,.$$

Lighting

Point light source - Model

For a point light source, there is a quadratic decrease in irradiance with distance. Every object that is smaller than the resolution of the camera can be considered as a point light source. Since objects are usually larger than the resolution of the camera, the quadratically increasing size of the area compensates for the quadratic decrease in intensity, and the brightness can be assumed to be independent of distance.

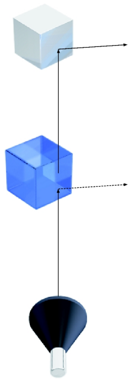


Optical Path - Brightness

Light is emitted from one or more light sources. It hits the objects with a certain irradiance. Depending on the surface properties and the transmittance of objects light is absorbed, refracted and reflected differently. A fraction of the scattered light hits the lens and affects the brightness of the imaged object.

A surface element receives not only direct light from the light sources, but also indirect light from all reflective surfaces in the scene.

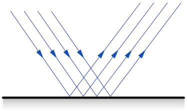
- Therefore, the brightness of a projected pixel depends on the position and reflection behavior of all objects in a scene.



Lighting

Surfaces - Reflections

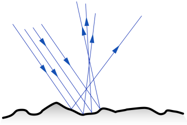
Directed reflection



- Incident light is reflected from the surface in one direction only.

Occurs on reflective surfaces and creates specular highlights that shift when the object or camera slightly change their poses.

Diffuse reflection

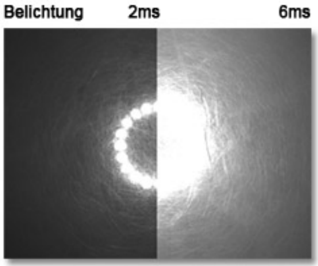


- Light is scattered from the surface in different directions.

A completely diffuse surface is also called Lambert radiator (all directions uniform). Most surfaces have a mixed scattering behavior, e.g. painted metal surfaces.

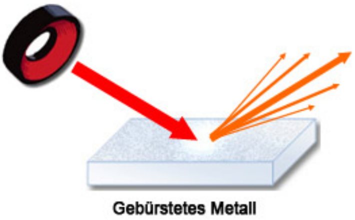
Lighting

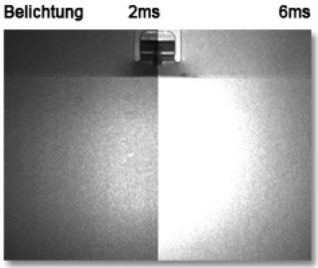
Surfaces - Glossy surface



Lighting

Surfaces - Metallic surface





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surfaces - Matte surface

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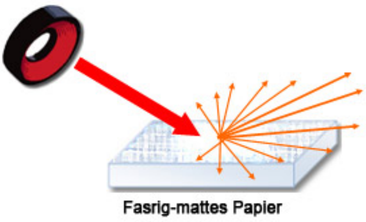
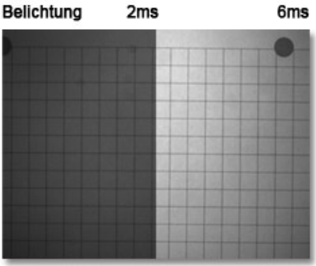




Lighting

Illuminant - Types

In principle, there are different types of lighting:

- daylight
- LED lighting
- halogen lamps
- neon tubes
- etc.

In many cases, LED lighting is preferable because of the characteristic properties, such as long life, mechanical robustness and ideal arrangeability. Their light color can be not only white, but also red, green or blue, infrared or ultraviolet.

Lighting

Illuminant - Examples

Daylight

Neon light

LED-light

Halogen light

Lighting

Types

By a proper choice of the lighting, disturbing reflections can be avoided.

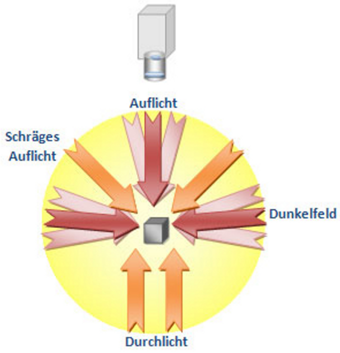
- Diffuse illumination Illumination that occurs from all directions.
- Dome illumination Homogeneous illumination (locally constant illumination field) that occurs from all directions.
- Coaxial illumination Directional illumination where the direction of illumination coincides with the direction of observation.
- Telecentric illumination Illumination of an object by parallel light beams.
- Dark field illumination Light is deflected into the imaging system only at task-relevant structures of an object. Everything else remains dark.
- Light field illumination The predominant part of an object surface causes a light deflection into the imaging system and appears bright.

Lighting

Types - Incident light & Transmitted light

All types of illumination can be transmitted or reflected light.

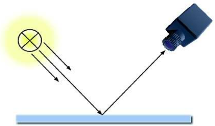
- Transmitted light Illumination which is in the half-space, which is opposite to the imaging optics with respect to the object ("behind the object").
- Incident light Illumination where the light source is located in the same half-space as the imaging optics with respect to the object ("in front of the object").

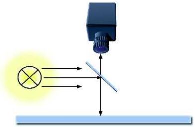


Lighting

Types - Incident light

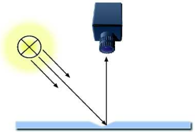
Light field illumination

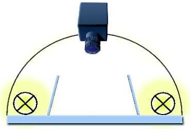




Coaxial lighting

Dark field illumination



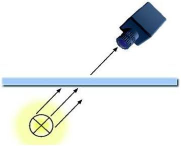


Diffuse illumination

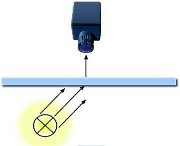
Lighting

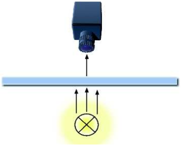
Types - Transmitted light

Light field illumination

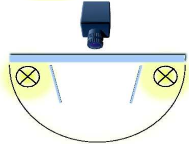


Dark field illumination





Coaxial lighting



Diffuse illumination

Lighting

Examples

diffuse illumination

coaxial illumination

diffuse, homogeneous illumination

(http://www.vision-doctor.de)

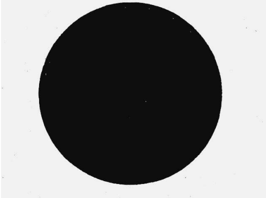
Lighting

Examples

direct incident light

diffuse incident light

dark field illumination



Transmitted light

Digital image Image acquisition systems

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Distinction between

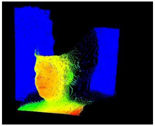
- passive and active camera systems
- different frequency ranges

Examples

- digital camera
  - area- & line scan camera
  - B/W & color camera
- Thermal imaging camera (infrared camera)
- Time-of-Flight Camera
- Dynamic Vision Sensor “Silicon Retina”

Time of flight camera

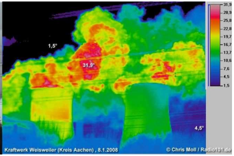
Depth



Intensity

Digital image

Thermal image



Digital camera

Image recording - Principle

For digital image recording, solid-state image sensors (mainly silicon-based), integrated semiconductor components arranged in the form of an area matrix, mostly based on CCD (Charge Coupled Devices) are used for digital image recording.

A CCD image sensor operates in three stages:

- The photons of the incident light are converted into a quantity of charge proportional to the illumination intensity (photoelectric effect). Integration time $\approx 20ms$.
- During the readout phase ($< 1ms$) the sequential transfer of the accumulated charge packets along a chain of MOS capacitors (transfer register, vertical shift register) to a readout stage takes place.
- In the readout stage, each incoming charge packet is converted into a voltage signal proportional to the charge quantity (A/D converter).

Digital camera

Image recording - Principle

Most often CCD area sensors are used in interline transfer mode:

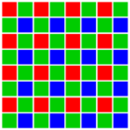
Other transfer modes: full frame and frame transfer.

(http://www.vision-doctor.de)

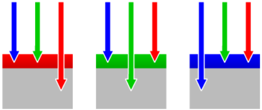
Digital camera

Color images - Bayer-Filter

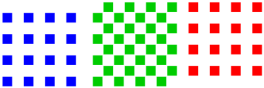
The Bayer filter is a color filter for a photo sensor, arranged like a chessboard, which consists of 50% of green, and 25% each of red and blue. The missing color values of the unoccupied pixels in the individual color channels must be generated artificially via interpolation. This leads to color errors at color discontinuities.



Bayer-Filter



Red 25% Green 50% Blue 25%

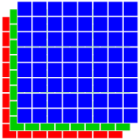


Color channels with missing values

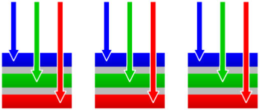
Digital camera

Color images - Foveon X3 Direct image sensor

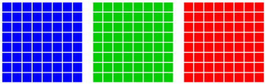
The Foveon X3 is a CMOS image sensor consisting of three superimposed layers of photodiodes. The different wavelengths of the colors red, green and blue are absorbed in different layers, because long-wave (red) light has a greater penetration depth in silicon than short-wave (blue) light. Each of the layers has its own color sensitivity. Thus, the color sensitivity of the human eye can be reproduced relatively well.



Three layers of photodiodes



Different absorption depths



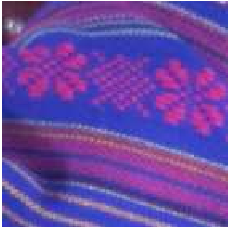
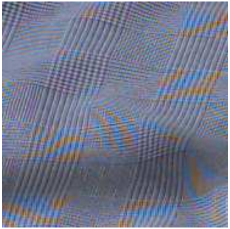
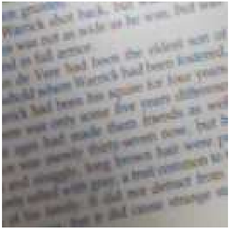
Dense color channels with different color sensitivity

(Quelle: http://www.foveon.com/)

Digital camera

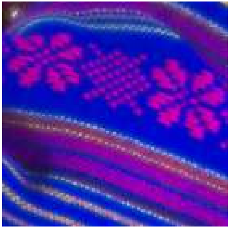
Color images - Comparison Bayer - Foveon X3

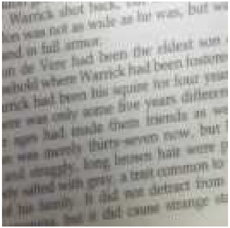
Bayer

Color representation | Aliasing-Effects | Depth of Sharpness

Foveon X3



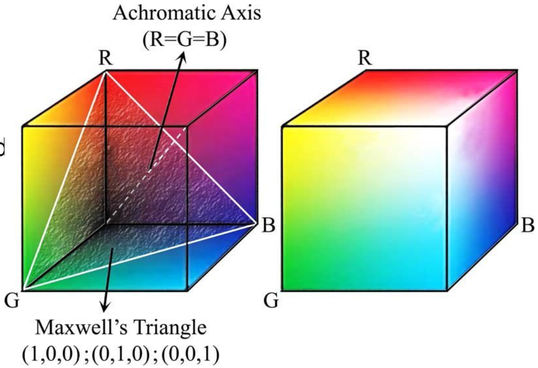


Color images

Color spaces - RGB and HSV

R: red channel
G: green channel
B: blue channel

The color channels correspond
different wavelength ranges of
visible light.

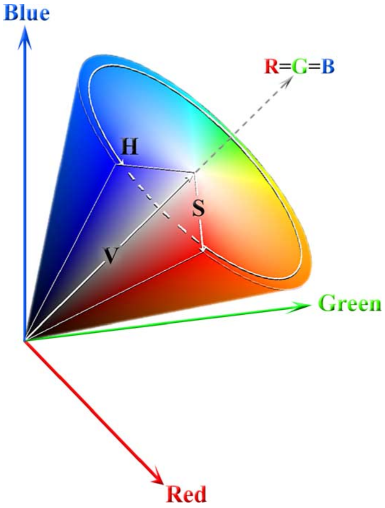


Color images

Color spaces - RGB and HSV

H: Hue, color
S: Saturation, grayness
V: Value, brightness

If one wants to segment a certain color in the image, the HSV space offers advantages because the individual color channels better reflect human color perception. One chooses a certain (small) color range, the desired (larger) saturation range (grayness) and a (large) brightness range.



Digital camera

digitizing errors - overview

- Image noise
- Smear & Blooming: Exceeding the amount of charge due to overexposure.
- Moiré-pattern: Periodic patterns on an object are undersampled due to an insufficiently resolved image rasterization. This results in “sham patterns” (aliasing effect).
- Compression artifacts e.g. jpeg

Blooming-Effect

Moiré-Effect

Jpeg-Artefacts

Digital camera

digitizing errors - Image noise

Reasons for image noise on CCD sensors

- Pixel variable dark current (e.g. due to temperature increase) and noise of the readout amplifier.
- Photon noise, variations of the light sensitivity of a pixel
- Pixel size and pixel pitch: the smaller the more noise
- Quantization noise
- Exposure time: The longer the more noise

low light sensitivity, little noise

high light sensitivity, more noise

Digital cameras

Operating principles

Line camera (industry standard)

Active 3D Sensors/Camera Systems

- Time-of-flight camera
- Structured light (industry standard)

Digital cameras

Line camera

Properties/Special features

- resolutions up to 12288 pixels in X-direction, in transport direction resolution is (almost) arbitrary
- camera or object must be moved
- simpler illumination (linear)
- higher illumination intensities can be realized
- use especially for scanners and inspection