Light perception by humans

Humans perceive approx. 90% of information about the environment by means of visual system.

Efficiency of the human visual system is characterised by a number of features:

- the ability to resolve image details ($\theta = 1' = 1^\circ/60 = \pi/10800$);
- the ability to discriminate between brightness levels (contrast sensitivity);
- colour perception;
- brightness adaptation;
Human visual system

- Retina: 125×10^6 receptors
- Cornea
- Iris
- Lens
- Optic nerve
- Optic chiasm
- Lateral geniculate nucleus
- Visual cortex
- Right visual field
- Left visual field
- Striate cortex V1

Modifed from J. M. Hudspeth, Polyak, 1957

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Structure of the human eye

- retina: $125 \times 10^6$ receptors
- Blind spot
- Fovea
- Visual axis
- lens
- iris
- Nerve

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Distribution of rods and cones in the retina

No of cones/rods per mm²

Angle
Binocular vision

Perception of depth (distance)

Eye convergence angle

Disparity in binocular vision

17 mm

~10 m
Role of colours in depth perception

The black line in the back seems much longer than the one in the front because your brain assumes it is seeing the effects of perspective. When the background is removed, the lines are seen to be equal.

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Electromagnetic spectrum

Frequency [Hz]

\[10^{24} \quad 10^{22} \quad 10^{20} \quad 10^{18} \quad 10^{16} \quad 10^{14} \quad 10^{12} \quad 10^{10} \quad 10^{8} \quad 10^{6} \quad 10^{4} \quad 10^{2}\]

- Gamma rays
- X rays
- Ultraviolet
- Visible spectrum
- Infrared waves
- Microwaves
- Radio waves
Spectral sensitivity characteristic of the human eye
Visual perception

Subjective brightness sensation assumes a logarithmic characteristic.

Human eye can perceive brightness in the range of $10^{10}$. 
Contrast sensitivity (Weber fraction)

The ratio $\frac{\Delta I}{I}$ is termed the Weber fraction. It reflects contrast sensitivity characteristic of the human eye.
The eye achieves maximum sensitivity for:

\[ I + \Delta I \approx I_0 \]
Mach bands

Brightness intensity

Subjective brightness
Visual illusions

- Zöllner Illusion (1860)
- Poggendorff Illusion (1860)
- Helmholtz’s Squares (1866)
- Müller–Lyer Illusion (1889)
- Hering Illusion (1861)
- Wundt Illusion (1896)
Image acquisition system
**Visual path of the image processing system**

**Visual path** – a set optical and electronic elements converting radiant energy into an electrical signal and imaging it using display devices.
Pros and cons:

- small hole → little light goes in
- large hole → image blurring
Cameras today

Pros and cons:

• sharp, high-contrast image
• geometric distortions
Image formation model

3D Image formation model

2D Image plane of the imaging sensor

\( (x, y) \) is the coordinate on the 2D image plane.

\( f(x, y) \) is the function representing the image formation process.
Image formation model

\[ f(x, y) = i(x, y) r(x, y) \]

- illumination \((x,y)\)
- reflectance coefficient at \((x,y)\)

**illumination:** sunny day \(\sim 5000 \text{ cd/m}^2\), cloudy day \(\sim 1000 \text{ cd/m}^2\), full moon \(\sim 0.001 \text{ cd/m}^2\),

**Reflectance coeff.:** black velvet - 0.01, white wall - 0.8, snow - 0.93.
For a linear process of energy accumulation in the image sensor plane:

\[ f(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(\alpha, \beta) h(x, y, \alpha, \beta) \, d\alpha \, d\beta \]

\( h(.) \) – is the impulse response of the system; in optical systems it is termed the point spread function of the system.
If the point spread function is shift invariant, then the image formation model is given by a convolution integral:

\[ f(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(\alpha, \beta) h(x - \alpha, y - \beta) \, d\alpha \, d\beta \]

where

\[ h(x, y) = \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right) \]
Sampling of 1-D signals

\[ f(x) \rightarrow x \]

\[ s(x) \rightarrow \Delta x \]

\[ s(x)f(x) \rightarrow \Delta x \]

\[ F(\omega) \rightarrow \omega \]

\[ S(\omega) \rightarrow \omega \]

\[ S(\omega) \ast F(\omega) \rightarrow \omega \]
Sampling of 2-D signals

Assume the source image (analog image) features a limited Fourier bandwidth
Sampling of 2-D signals

Image sampling function:

\[ S(x, y) = \sum_{i=0}^{M-1} \sum_{k=0}^{N-1} \delta(x - i\Delta x, y - k\Delta y) \]

and a sampled image:

\[ f_s(x, y) = f(x, y)S(x, y) = \sum_{i=0}^{M-1} \sum_{k=0}^{N-1} f(i\Delta x, k\Delta y)\delta(x - i\Delta x, y - k\Delta y) \]
Sampling of 2-D signals

Fourier spectrum of the sampled image:

\[
F_s(\omega_x, \omega_y) = \frac{1}{\Delta x \Delta y} \sum_{i=0}^{M-1} \sum_{k=0}^{N-1} F(\omega_x - i\Delta \omega_x, \omega_y - k\Delta \omega_y)
\]

where:

\[
\Delta \omega_x = \frac{1}{\Delta x}, \quad \Delta \omega_y = \frac{1}{\Delta y}
\]
Sampling of 2-D signals

\[ \Omega_{\text{max}} < \frac{\Delta \omega_x}{2} = \frac{1}{2\Delta x} \]

\( \Delta \omega_x \)

\( \Delta \omega_y \)

\( \omega_{\text{max}y} \)

\( \omega_{\text{max}x} \)

image bandwidth
Aliasing distortion - example

Scanned images:

500 dpi

100 dpi

(dots per inch)
Image acquisition

Image acquisition is the process of converting light energy radiating from image scene points into an electrical signal (suitable for storing or transmission).

Image acquisition devices:

- CCD camera
- Video camera
- Scanner
- Digitizer
There are two basic schemes of converting optical images into electrical signals:

- **without accumulation of photo-charges** (eg. optical scanner),
- **with accumulation of photo-charges** (np. vidicon, CCD array)
Imaging sensor (no photo-charges)
CCD array (accumulation of photo-charges)

Image formation is based on the internal photo-electric phenomenon

Capacitor cell
The Bayer matrix

Raw CCD Format

Calculate RGB image by interpolating colour components from the Bayer matrix
Pixim – Digital Pixel System (DPS)

A/D converter for each pixel (no charge couplings)  Single A/D converter
CMOS image sensors

Pros:
- cheap technology (used for fabricating memory and CPU modules),
- low power consumption (100 times!)
- random access to pixel regions (block image processing)
- no "charge leaking" typical for CCD technology
- on-chip analog-to-digital conversion and signal processing

Cons:
- more susceptible to noise than CCD
- lower light sensitivity due to many transistors used for single pixel
Monochrome TV standards

- European **CCIR** standard: (625 (575) lines, line display time 64us, 50 half-images per sec., 1Vpp, 75Ω, signal

- American **RS170** standard: (525 (484) lines, line display time 63,5 us, 60 half-images per sec., 1.4 Vpp, 75Ω signal

- American **RS-343** standard”: (875 lines, 60 half-images, dedicated to CCTV, scientific applications,...)
TV CCIR standard

625/575 lines

odd lines
even lines

1. Odd lines
2. Even lines
3. Peak white level
4. Video signal
5. Blanking level
6. Sync level
7. Horizontal sync pulse

Horizontal sync pulse:
- 64 µs duration
- 0 V (DC)
- 0.7 V
- -0.3 V
Resolution:
RS-170A: 580 horizontal TVL, 350 vertical TVL; CCIR: 560 horizontal TVL, 450 vertical TVL
Synchronization:
Crystal/H&V/Asynchronous, standard
Shutter: 1/60 to 1/10,000
AGC: 20 dB
Integration: 2 - 16 Fields
Sensitivity:
Full video, No AGC: 0.65 lux; 80% video, AGC on: 0.04 lux; 30% video, AGC on: 0.008 lux
S/N Ratio (Gamma 1, gain 0 dB): 55 dB

Specification Highlights
Imager:
1/2" interline transfer CCD
Picture Elements:
RS-170A: 768 (H) x 494 (V); CCIR: 752 (H) x 582 (V)
Pixel Cell Size:
RS-170A: 8.4 µm (H) x 9.8 µm (V); CCIR: 8.6 µm (H) x 8.3 µm (V)
CCD image sensors characteristics

- small size,
- robust to mechanical vibrations (70 G),
- no geometrical distortions,
- low supply voltage (12 V, 1.4W),
- SNR ~70 dB,
- linear (gamma coefficient),
- no intra-frame photo-charge accumulation,
- high resolution,
- reliable
- cheap
Matrox CronosPlus

Video capture board for PCI captures from **NTSC**, **PAL, RS-170** and **CCIR** video sources, connect up to 4 CVBS or 1 Y/C trigger input, 7 TTL auxiliary I/Os, 32-bit/33MHz PCI-bus master

Software is sold separately, includes e.g., **Matrox © Imaging Library** for Microsoft® Windows®