A continuous image is 2D function

1D: f(t) is a function f that depends on the time t.
2D: f(x,y) is a function f that depends on the spatial (room) coordinates x and y.

Ex)

\[ f(x,y) = \sin(x - y) + 1 \]
\[ f(x,y) = 0 \implies \text{black} \]
\[ f(x,y) = 2 \implies \text{white} \]
The digital image sensor

Fig. 2.12

Single sensor element:

Line sensor:

Array sensor:

The digital image acquisition process

Fig. 2.15

Typically a camera

Image sampling and quantization

Fig. 2.16

Continuous Image

Line from image

After sampling

After quantization

The digital image sensor

For a color image, there are 3 different types of sensor elements: red, green and blue

Fig. 2.17

A continuous image projected onto the sensor array

Result after sampling and quantization
Representation of a digital image

Saturation and noise

Spatial resolution

Spatial resolution

Saturation is the highest value beyond which all intensity levels are clipped.

Noise appears often as a grainy texture.

- Spatial resolution is a measure of the smallest discernible detail in the image.
- Two common measures: lp/mm, dpi
  - Newspaper: 75 dpi
  - Magazine: 133 dpi
  - Glossy brochures: 175 dpi
  - Gonzalez & Woods: 2400 dpi

5 discernible line pairs (lp) per mm, 5 lp/mm
6 dots per inch, 6 dpi

A newspaper image

1250 dpi 3692 x 2812 pixels
300 dpi 886 x 675 pixels
150 dpi 443 x 337 pixels
72 dpi 213 x 162 pixels

Fig. 2.18

Fig. 2.20

Fig. 2.23
Intensity resolution

- We can only resolve $2^8 = 64$ (or $2^7 = 128$?) intensity levels on an ordinary computer screen.
- Based on hardware considerations, gray scale images are usually stored with 8 bits per pixels, i.e. $2^8 = 256$ intensity levels.
- Some images are stored with more than 8 bits per pixels. CT images, for example, are stored with 12 bits per pixels, i.e. $2^{12} = 4096$ intensity levels.
- During calculation and image processing, pixels can preferably be stored with more than 8 bits or floating point numbers.
- Special hardware utilized for fast calculation sometimes store a pixel with less than 8 bits.
- Color images are usually stored with 3x8 bits per pixels, $2^8$ red intensity levels, $2^8$ green intensity levels and $2^8$ blue intensity levels giving $2^{24} = 16$ million different colors.

The same CT image, shown in 2 different contrast windows

The electromagnetic spectrum
Imaging – the creation of images
Examples of different sources

- Electromagnetic radiation
  - Transmitted gamma-rays, fig. 1.6a
  - Transmitted and reconstructed gamma-rays, Single Photon Emission Tomography, SPECT
  - Emitted and reconstructed gamma-rays, Positron Emission Tomography, PET, fig. 1.6b, slide 28
  - Transmitted X-rays, fig 1.7a,b
  - Transmitted and reconstructed X-rays, Computed Tomography, fig. 1.7c, slide 14, 19
  - Excitation rays from ultraviolet light, fluorescence microscopy, fig. 1.8a,b
  - Reflected rays from visible light, slide 4, 10, 12, 23
  - Reflected infrared rays, slide 17,
  - Emitted radio waves + magnetic fields and reconstruction => magnetic resonance imaging (MRI), fig 1.17

- Ultrasound
  - Transmitted and reflected ultrasound, fig 1.20

Image Reconstruction: To compute an image from the in-signal. Ex: Computed Tomography (CT).
Examples of different images from different sources

Fig. 1.7ab
Transmitted X-rays

Fig. 1.8ab
Fluorescence microscopy

Examples of different images from different sources

Fig. 1.17
MRI

Fig. 1.20ab
Transmitted and reflected ultrasound

Gray scale image compared to true color image

Matlab:
Colim = zeros(450,600,3);
Colim(:, :, 1) = R; Colim(:, :, 2) = G;
Colim(:, :, 3) = B;

True color image: Colim

Gray scale image: Grayim

Grayim = 0.2989 * R + 0.5870 * G + 0.1140 * B;
Grayim = rgb2gray(Colim);

Landsat’s images combined to color images

3, 2, 1 = R,G,B
combined to color image

4, 2, 1 = R,G,B
combined to pseudo-color image
Color maps

- Sometimes, the pixels are quantified to the interval [0,255]. These values are transformed through a color map in the computer to:
  - Gray scale values, i.e. 0->black and 255->white or
  - Arbitrary colors (pseudo colors)

- Sometimes, the pixels are floating point values. These values are transformed to the interval [0,255] and further through a color map in the computer.

- A true color image has 3 values per pixel. These values are transformed individually through 3 color maps in the computer and further to the red, green and blue channel of the screen.

Normal gray scale color map

Pixel value f(x,y)

<table>
<thead>
<tr>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

A D/A-converter converts a digital value to an analog value, an electrical voltage.

To D/A-converter and further to the screen.

True Color map

Pixel value \([f_r(x,y), f_g(x,y), f_b(x,y)]\)

- Linear transformation

<table>
<thead>
<tr>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
</tbody>
</table>

Over 16 million colors

To D/A-converter and further to the red channel of the screen.

To D/A-converter and further to the green channel of the screen.

To D/A-converter and further to the blue channel of the screen.

Pseudo-color map

Pixel value f(x,y)

<table>
<thead>
<tr>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
</tbody>
</table>

A PET-image shows where it is activity in the brain. High activity is shown red and low activity is shown blue.
Additive color mixing.

Additive color mixing.

- Yellow = red + green
- Cyan = green + blue
- Magenta = red + blue

Lab 5

Later Lecture: Much more on color

Basically, the eye works rather much like a camera... 😊

- Reflect light from the palm tree
- Lens
- Focal length
- The retina is the sensor

- But the brain performs some more processing that gives rise to visual phenomena...

Visual phenomenon 1: The Mach band effect

- Gray scale image:
- Actual intensity:
- Perceived intensity:

Visual phenomenon 2: Simultaneous contrast

- All the inner squares have the same intensity, but they appear progressively darker as the background becomes brighter, which are seen when the red frames are removed.
Application examples: Automated visual inspection of manufactured goods

- Controller board
- Pill container
- Bottles filling level
- Air pockets in plastic

Some more application examples

- Finger print
- Paper currency
- Automated license plate reading

The book (3:rd ed) and the course

- Multidimensional Signal Analysis TSBB06
- Image and Audio Coding TSBK02

Outlines of these processes generally on images

- Included
- Partly included
- Not included

Image sensors TSBB09

- Color image processing
- Wavelets and other image transforms
- Morphological processing
- Image restoration (Reconstruction)
- Image filtering and enhancement
- Feature extraction
- Image pattern classification

Feature extraction

Knowledge base

Outputs of these processes generally on images

Question for next lecture:

What is negative frequency in the Fourier transform?

- 1. \( \sin(-2\pi u) \) is an example of a signal with negative frequency.
- 2. \( -\sin(2\pi u) \) is an example of a signal with negative frequency.
- 3. The frequencies in the Fourier transform have no relation to real frequencies.
- 4. ...