Lecture 6 in Computerized Image Analysis
Digital Color Processing

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Reading instructions:
Chapter 6
The slides
Visible light (for humans) is electromagnetic radiation with wavelengths in the approximate interval of 380-780 nm.
Light Properties

Illumination

» Achromatic light - “White” or uncolored light that contains all visual wavelengths in a “complete mix”.
» Chromatic light - Colored light.
» Monochromatic light - A single wavelength, e.g., a laser.

Reflection

» No color that we “see” consists of only one wavelength
» The dominating wavelength reflected by an object decides the “color tone” or hue.
» If many wavelengths are reflected in equal amounts, an object appears gray.
The Human Eye

Rods and Cones
(stavar och tappar)

The first light sensing organs appeared 540 million years ago
The Rods

- Approx. 100 million rod cells per eye
- Light-sensitive receptors
- Used for night-vision
- **Not used for color-vision!**
- Rods have a slower response time compared to cones, i.e. the frequency of its temporal sampling is lower

Some calculations suggest the resolution of the eye to be 9000 x 9000 pixels
The Cones

- Approx 5 million cone cells per eye
- Three types:
  - S, peak at 445 nm (2%)
  - M, peak at 535 nm (33%)
  - L, peak at 575 nm (65%)
- Most sensitive to green light!
Mantis shrimp
bönsyrseräka

12 type of color receptors!

www.nwf.org/nationalwildlife/article.cfm?issueID=77&articleID=1114
Remark about our Vision

The appearance of an object’s intensity depends on the surroundings; the sensation is relative and not absolute.
Trisimulus Values

- CIE, International Commission on Illumination
- 2°/10° standard observer

CIE XYZ values

\[ X = \int s(\lambda) r(\lambda) x(\lambda) d\lambda \]
\[ Y = \int s(\lambda) r(\lambda) y(\lambda) d\lambda \]
\[ Z = \int s(\lambda) r(\lambda) z(\lambda) d\lambda \]

standardized light source

reflectance of the object

CIE 1931 standard observer

\( s(\lambda) \)
\( r(\lambda) \)

400nm 700nm

400nm 700nm

400nm 700nm

\( X = 14.27 \)
\( Y = 14.31 \)
\( Z = 71.52 \)
**CIE 1931 Color Space**

- The projection of $X + Y + Z = 1$ creates CIE $xy$ chromaticity diagram.
- CIE standard white when $x = y = z$.
- Not possible to produce all colors by mixing three primary colors.

**Gamut**: subset of colors which can be accurately represented in a given circumstance.
RGB: Red, Green, Blue

Additive mix

\[ R + G + B = \text{White}, \]

where \( R + G = Y, \) etc.

%RGB in matlab
\[
\text{rgbImg} = \text{imread('colorful.jpg')};
\text{Rchannel} = \text{rgbImg}(:,1); %uint8
\text{Gchannel} = \text{rgbImg}(:,2); %uint8
\text{Bchannel} = \text{rgbImg}(:,3); %uint8
\]
Additive Mix

R channel  G channel  B channel

Uppsala  Uppsala  Uppsala

RGB: Uppsala
**CMYK**

- \([C \ M \ Y]^- = 1 - [R \ G \ B]^-\)
- Subtractive mix \(C + M + Y = black\)
  - where \(C + M = B\), etc
- Common in printing

![The CMY cube](image-url)
RGB - Pros & Cons

- Mimicking the human color perception
- Easy and straightforward
- Suited for hardware implementation

- Not practical for human description of colors
- No decoupler of intensity
**HSV (HSI)**

- Related to how humans perceive color
- Intensity is decoupled
- Channels:
  - **Hue**: dominant wavelength (in degrees!)
  - **Saturation**: colorfulness (intensity of the color)
  - **Intensity/Value**: brightness

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```matlab
% HSV in matlab
rgbImg = imread('colorful.jpg');
hsvImg = rgb2hsv(rgbImg);
Hchannel = hsvImg(:,:,1); % double
Schannel = hsvImg(:,:,2); % double
Vchannel = hsvImg(:,:,3); % double
```
RGB to HSV

\[
H = \begin{cases} 
\theta & \text{if } B \leq G \\
360 - \theta & \text{if } B > G 
\end{cases}
\]

\[
\theta = \cos^{-1} \left( \frac{1}{2} \frac{(R-G)+(R-B)}{\sqrt{(R-G)^2+(R-B)(G-B)}} \right)
\]

\[
S = 1 - \frac{3 \min (R, G, B)}{R + G + B}
\]

\[
V = 0.2126 \ R + 0.7152 \ G + 0.0722 \ B
\]
or

\[
V = \frac{1}{3} (R + G + B)
\]

for \( s = 0 \) not defined!

There are also other definitions!
HSV

H channel

S channel

V channel

HSV:
Usage of HSV

- Intensity is decoupled
  - That’s often where we want to “operate”

Original image
RGB image histogram equalized for each channel individually
HSV image histogram equalized for the V-channel only
**HSV usage, cont**

**Masking out a region with similar color**

- Find the pixels in the range of the desired color in the **Hue**-channel
- Set all other pixels to 0 in the **Saturation**-channel

```matlab
%imgHSV : HSV-transformed image
%masked H-value: 0-0.1 and 0.9-1.0
mask = (imgHSV(:,:,1) < 0.1) 
    + (imgHSV(:,:,1) > 0.9);
S = imgHSV(:,:,2) .* mask;

imgHSV_r (:,:,3) = imgHSV(:,:,3);
imgHSV_r (:,:,2) = S;
imgHSV_r (:,:,1) = imgHSV(:,:,1);
```
HSV usage, cont

Another example

- Find the pixels in the range of the desired color in the Hue-channel
- Set all other pixels to 0 in the Saturation-channel

```matlab
%imgHSV : HSV-transformed image
%H-value of the tree : 0.15-0.27
mask = (imgHSV(:,:,1) < 0.15)
    + (imgHSV(:,:,1) > 0.27);
S = imgHSV(:,:,2).* (1-mask);

imgHSV_g(:,:,3) = imgHSV(:,:,3);
imgHSV_g(:,:,2) = S;
imgHSV_g(:,:,1) = imgHSV(:,:,1);
```
HSV- Pros & Cons

- Practical for human description of colors
- Intensity decoupled

- Difficult transformation (singularities)
- Difficult to display

Furthermore: Not device independent (the latter also applies to RGB)
CIE L*a*b*

- Device independent
- Perceptually uniform
- Intensity decoupled

Studies indicate that L*a*b* separates information better than other color spaces.

For transformation, see 6.5.4 in the course book.

Perceptual equal distances
L*a*b*

L* channel

a* channel

b* channel

L*a*b*:
Other Color Spaces

- **YCbCr** – similar to L*a*b*
  - Used for JPEG
  - Uses the fact that the human eye is more sensitive to variations in lightness than variations in hue and saturation, and more bandwidth (bits) is used for Y.

- Similar color spaces: **YIQ / YUV** used for TV

**Y**: the luma
Cb: balance of blue-yellow
Cr: balance of red-green
Pseudo Coloring

- The eye can distinguish between only about 30-50 different shades of gray
- But about 100,000 – 10,000,000 colors.
- Useful to display gray scale images using color to visualize the information better
- Important to include a color scale in the images to understand what the colors illustrate.

It seems rather cumbersome to measure the number of distinguishable colors by humans. Follow the discussion at: http://hypertextbook.com/facts/2006/JenniferLeong.shtml
Example of Pseudo-Coloring in PET

- Intensity slicing
  - Each intensity is assigned a color
Another Example of Pseudo-Coloring

Lake Mälaren, 1997

chlorophyll  suspended inorganic particulate material  coloured dissolved organic matter
Noise in Color Images

Noise less visually noticeable in color images

\[ \mu = 0, \nu = 0.01 \] Gaussian Noise

Grayscale image (on V only)  RGB (each channel distorted individually)
Noise in the HSV-space

Noise most visible in the H- and S-channel
Smoothing

Neighborhood averaging can be carried on a per-color-plane basis - or on the intensity only.

Different results however! See below:

Original

HSV (on V only)

RGB (each channel filtered individually)
Look out for the H-channel

- You might end up with **color artefacts** if H-channel is filtered
- Remember: H-channel consists of angles 0-360°

H-channel blurred with a 3x3 Gaussian
Edge Detection

As in smoothing: per-color-plane / intensity channel
Segmentation based on Color

In RGB-space: Look at the euclidean distance:
\[ D(z, a) = \|z - a\| \]
\[ = [(z_R - a_R)^2 + (z_G - a_G)^2 + (z_B - a_B)^2] \]

If \( D(z, a) < Dt \): Pixel belongs to the object

Color-based segmentation in HSV-space: color information is found in the Hue- & Saturation-channel
Segmentation based on Color

Example:

Original

Segmented sky

Uppsala
Compression of Color Images

- Our vision is less sensitive to fine color details than to fine brightness details
- Concentrate the compression on the chroma (color) information

More about compression in lecture 16
Multispectral Imaging

A more general description of an image:

- \( f(x,y,z,w,t) \)
- \( x,y,z \) – 3 spatial dimensions
- \( t \) – time - temporal dimension
- \( w \) – wavelength, spectral dimension

Images in sampled in different wavelengths

- Not only in the visible spectra
- Remember the shrimp?
Multispectral imaging cont.

- Used in (among others)
  - Remote sensing
  - Astronomy
  - Thermography
Assignment 3

- **Landsat Satellite Image:** 7 Bands, 0.45-12.5 um
  - from the visual spectra to IR
- **Your data:** 512 x 512 x 7