Introduction to Medical Image Analysis

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Plenty of slides adapted from Thomas Moeslunds lectures
# Week 3 – Pixelwise operations

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What can you do after today?

- Compute and apply a linear gray transformation
- Describe and compute the image histogram
- Implement and apply histogram stretching
- Implement and apply gamma transformation
- Implement and apply log and exp mappings
- Describe and use thresholding
- Describe and use automatic thresholding
- Perform conversions between bytes and doubles
- Use addition and subtraction of images
- Explain the benefits of bi-modal histograms
- Identify images where global thresholding can be used for object extraction
Gray value mappings

- Mapping
  - To make correspondence between two sets of values
- Look-up-table
  - A table of mappings

<table>
<thead>
<tr>
<th>0</th>
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<tr>
<td>5</td>
<td>17</td>
<td>53</td>
<td>75</td>
<td>99</td>
<td>180</td>
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Gray value mappings

- Mapping
  - To make correspondence between two sets of values

- Mapping function
  - out = f(in)
  - f(0.5)?
Mapping function

A) 0.1
B) 0.2
C) 0.3
D) 0.4
E) 0.5

\[ f(0.5) = ? \]
Gray value mappings

- **Mapping**: To make correspondence between two sets of values

- **Mapping function**: out = f(in)
  - f(0.5)?

- **What happens with the values?**
  - Values with difference 0.1
  - Output values “spread out”
Why change gray level values

When could it be good to change the gray level values?

- Lack of contrast
- Make the image lighter
- Make the image darker
Point processing

- The value of the output pixel is only dependent on the value of one input pixel
- A global operation – changes all pixels
Point processing

- Grey level enhancement
  - Process one pixel at a time independent of all other pixels
  - For example used to correct Brightness and Contrast
    - Known from the television remote control

Correct  Too high brightness  Too low brightness  Too high contrast  Too low contrast
Brightness

- The brightness is the intensity
- Change brightness:
  - To each pixel is added the value $b$
  - $f(x, y)$ is the input image
  - $g(x, y)$ is the (enhanced) output image
- If $b>0$: brighter image
- If $b<0$: less bright image

$$g(x, y) = f(x, y) + b$$
Brightness

![Graphs showing brightness transformations](image)

- $g(x,y)$, $b = 0$
- $g(x,y)$, $b = 75$
- $g(x,y)$, $b = -100$
Contrast

- The contrast describes the level of details we can see
- Change contrast
- Each pixel is multiplied by \( a \)
  - \( f(x, y) \) is the input image
  - \( g(x, y) \) is the (enhanced) output image
- If \( a > 1 \) => more contrast
- If \( a < 1 \) => less contrast

\[
g(x, y) = a \times f(x, y)
\]
Combining brightness and contrast

- A straight line
- Called a *linear transformation*
- Here $a = 0.7$ and $b = 20$

$$g(x, y) = a \cdot f(x, y) + b$$
Linear transformation

\[ g(x, y) = a \times f(x, y) + b \]

\( a = 0.7 \) and \( b = 20 \)

\( \text{In} = 75 \)

A) 20
B) 45
C) 72
D) 103
E) 230
Linear transformation II

$a = 0.7$ and $b = 20$

$In = 150$

A) 34  
B) 65  
C) 125  
D) 198  
E) 210

$$g(x, y) = a \times f(x, y) + b$$
Combining brightness and contrast

- A straight line
- Called a linear transformation
- Here $a = 0.7$ and $b = 20$
- What will the result be on the output image?
  - More bright ($b > 0$)
  - Less contrast ($a < 1$)

$$g(x, y) = a \ast f(x, y) + b$$
Histogram Reminder

- A histogram normally contains the same number of “bins” as the possible pixel values.
- A bin stores the number of pixels with that value.

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Opgave 10.8

Hvilket histogram hører til billedet, der ses i Figur 6:

![Histogram Image]

A) A  
B) B  
C) C  
D) D  
E) E
Back to the histogram

- The shape of the histogram tells us a lot!
Histogram inspection

Dark image

Bright image
Histogram inspection

Low contrast

High contrast
How do we optimise the image using the histogram?
- Minimum and maximum values?
- Stretch it so new minimum = 0 and new maximum = 255
Histogram stretching

A) Using brightness
B) Using contrast
C) Using brightness and contrast
Histogram stretching

- We want
  - Min = 0
  - Max = 255

- We have
  - Min = 32
  - Max = 208

- Using brightness?
- Using contrast?
- Brightness and contrast!

\[ g(x, y) = \frac{v_{\text{max},d} - v_{\text{min},d}}{v_{\text{max}} - v_{\text{min}}} (f(x, y) - v_{\text{min}}) + v_{\text{min},d} \]
Histogram stretching formula

\[ g(x, y) = \frac{v_{\text{max},d} - v_{\text{min},d}}{v_{\text{max}} - v_{\text{min}}} \cdot (f(x, y) - v_{\text{min}}) + v_{\text{min},d} \]

- Desired min value \( v_{\text{min},d} = 0 \)
- Desired max value \( v_{\text{max},d} = 255 \)
- Current min value \( v_{\text{min}} = 32 \)
- Current max value \( v_{\text{max}} = 208 \)
Histogram stretching

\[ g(x, y) = \frac{255}{176} (f(x, y) - 32) \]
Effect of histogram stretching

![Image of bone structures before and after histogram stretching with corresponding histograms.]
Histogram stretching – weaknesses

- A single pixel value of 0 or 255 ruins it
- Sometimes you want
  - To stretch only the high pixel values
  - While “compressing” the low pixel values
  - Non-linear mapping
Opgave 10.25

Der udføres en linear mapping på billedet i Figur 16 hvor resultatet er et ny grayscale billede med maksimum værdi 255 og minimum værdi 0. Hvad er den nye værdi af den pixel, der har værdi 108?

1. 95
2. 111
3. 98
4. 119
5. 101
6. Ved ikke
Other mappings

- Non-linear mappings
- Not always nice to work with byte images
  - Better to work with image with values in $[0,1]$
Working with bytes and doubles

- A byte contains integer values $[0, 255]$  
  - A byte can not store $127.4232$
- A value of type `double` can contain “all numbers”
- Why not use doubles always?  
  - One double = 8 bytes in the memory  
  - Images become very large!  
  - Many things can be done with bytes
Map pixels to \([0,1]\)

- In Matlab it is easiest to create a new image of type double
  - \(I_{\text{temp}} = \text{double}(I)\);
  - (temp means temporary and is used by many programmers for variables that quickly are thrown away)

- Conversion to \([0,1]\)

\[
g(x, y) = \frac{1}{255} f(x, y)
\]
Pixels back to bytes

- Input pixels are [0,1]
- We want them to be [0,255]
- Simple linear transformation equal to
  - Contrast?
  - Brightness?

\[ g(x, y) = 255 \times f(x, y) \]

- Back to bytes
  - \( I_{\text{final}} = \text{uint8}(I_{\text{temp}}) \)
Gamma mapping

- Gamma mapping is used in televisions and flat panels
- Can increase the contrast (dynamics) in more selected part of the histogram
- Many games have a possibility for a gamma correction
Gamma curves

- Names after the Greek letter gamma
- What happens to the dark areas
  - With 0.45?
  - With 2.22?

\[ g(x, y) = f(x, y)^\gamma \]
Perform the gamma mapping

Conversion to [0,1] → Gamma mapping → Back to bytes → Byte image
Results of gamma mapping

0.45

2.22
Opgave 10.3

Der udføres en *gamma mapping* med $\gamma = 1.3$ på billedet i Figur 3. Resultatet er et ny grayscale billede. Hvad er den mindste og største pixelværdi i det nye billede?

1. 0 og 255
2. 25 og 130
3. 8 og 242
4. 15 og 230
5. 37 og 219
6. Ved ikke
Logarithmic mapping

Why?

Maps from $[0,255]$ to $[0,255]$
Logarithmic mapping – when?

- For images with very bright spots
- Low intensity pixel values are enhanced
What do we get out of pixel mappings

- Spreading out or compressing pixel values
  - Better for humans to see
  - New information – no!
Now for something different

- Until now image processing
  - Input image transformed to output image
- Now for something more like image analysis
- Segmentation
  - Segment the image into regions
    - Background and objects for example
Thresholding

- A threshold $T$ is a value
  - Pixels below that value is set to 0 (background)
  - Pixels equal or above is set to 1 (object)

- One threshold value for the entire image
  - Difficult to choose!

\[
\text{if } f(x, y) \leq T \text{ then } g(x, y) = 0 \\
\text{if } f(x, y) > T \text{ then } g(x, y) = 255
\]
Thresholding

Background and bone have same value!
Thresholding based on the histogram

The bones are visible in the histogram!
But mixed with soft-tissue
Automatic Tresholding
Automatic Thresholding

- Two classes: background and object
- T divides pixels into object and background
- Compute pixel value variance in each class
- Find T that minimises combined variance
Segmentation – histogram shaping

- With a threshold you want a histogram with two peaks – *Bimodal*
- An ideal histogram has well separated peaks
- Obtaining a bi-modal histogram is very important in the image acquisition

Ideal

Background

Object
Histogram shaping

- It is not possible to “unmix” using gray level transformations

- Should be higher
- Should be lower
How to obtain good histograms

- With cameras
  - Light
  - Setup
  - Camera
  - Lens
  - Backlight?
Opgave 14.19

Der udføres en *gamma mapping* med $\gamma = 1.1$ på billedet i Figur 12 og herefter sættes der et *threshold* på 120. Pixels over threshold sættes til forbundt og resten til baggrund. Hvor mange forgrundspixels er der i resultatbilledet?

A) 5
B) 2
C) 10
D) 7
E) 12
Contrast in medical images

- How do we optimise image acquisition when we want to look at
  - Bones
  - Brain structures
  - Cancer
Image acquisition - bone

- X-rays
  - goes through soft tissue with little loss
  - are attenuated in bone
- CT scanners use X-rays
  - Good for imaging bones
- A simple threshold can often extract the bones
- Areas with only bone and soft-tissue will have a bimodal histogram

Attenuation - the gradual loss in intensity
Image acquisition – brain structures

- Magnetic Resonance Imaging (MRI) is often used
- Much more difficult to explain!
  - Based on very powerful magnetic fields and radio waves
- Needs water molecules!
- Bone is black!
Image acquisition - cancer

- CT scan
- Liver cancer
  - Very difficult to see
What makes cancer cells special?
Cancer metabolism

- Cancer cells typically have a high metabolism
  - They eat more!

- Some substances are easier to see on different scanners
  - Bone on CT
Using the cancer metabolism

- Something that is to see
- Something that is being eaten by the cancer
- A tracer
Contrast using tracers

- A commonly used tracer is
  - $^{18}$F-FDG = 18F-fluorodeoxyglucose
- Used in oncological PET
  - Oncology: Cancer
  - PET: positron emission tomography
- Positron-emitting radioactive isotope fluorine-18
- Glucose is a “sugar”
PET

Wikipedia
PET Image

- Areas with high glucose intake will be brighter
  - Higher intake of radioactive molecules
- Bimodal histograms in areas with cancer cells
- Big research topic

Wikipedia
High-Resolution PET scanner at Rigshospitalet

PhD project by Oline Vinter Olesen – now startup
Combining Images

- CT is good for bone
- PET is good for cancer
- What if I want to see both?
- PET/CT scanner
  - Patient scanned in both a CT and a PET scanner

- Image registration
  - Take two or more separate images
  - Combine them using image registration
  - More about that later
Thresholds visited

- The tumour became much more separated from the background
- Perhaps a simple threshold is enough now?
- The best solution
  - Clever imaging techniques and
  - Intelligent image analysis
What can you do after today?

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Niveau af undervisning

A) Alt for let
B) For let
C) Passende
D) For svært
E) Alt for svært
Øvelserne

A) Alt for lette
B) For lette
C) Passende
D) For svære
E) Alt for svære
Brug af Clickers

A) Jeg har fået nok – ik’ mere
B) Lidt mindre tak
C) Passende
D) Jeg vil godt have mere
E) Mer’ mer’ mer
Next week

- Neighbourhood processing
  - Filtering
Exercises