Medical Image Processing

4 Operations in Intensity Space

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Table of Contents

Overview

Overview

Intensity Transform Function and Dynamic Range

The easiest way to transform image intensities is a linear transform, which is given below:

$$\rho^{'} = \frac{\rho - \rho_{min}}{\rho_{max} - \rho_{min}} \omega_{target} + \rho^{'}_{min}$$

$\rho^{'} \cdots$ transformed pixel intensity
$\rho \cdots$ original pixel intensity
$\rho_{min}, \rho^{max} \cdots$ minimum and maximum gray values in the original image
$\omega_{target} \cdots$ range of the target intensity space

Intensity Transform Function and Dynamic Range

Figure: The original image from Section 2.7.1 (left), and a version with optimized gray scale representation (middle). The contrast transform function is shown to the right; it is actually a screen shot of the corresponding dialogue in the GIMP. The original intensity range is shown on the x-axis of the intensity transform(ITF). The curve shows how a gray value in the original image is translated to an optimized gray scale range(which can be found on the y-axis of the ITF)

Intensity Transform Function and Dynamic Range

A model of a Sigmoid-based ITF which transforms gray scale images of unsigned 8-bit depth is given below:

$$S(\rho) = 255 \frac{1}{1+e^{-\frac{\rho-\omega}{\sigma}}}$$

$\rho \cdots$ 8 bit gray value
$\omega \cdots$ Center of the gray value distribution; for 8-bit images, choose $\omega = 127$
$\sigma \cdots$ Width of the gray value distribution

Intensity Transform Function and Dynamic Range

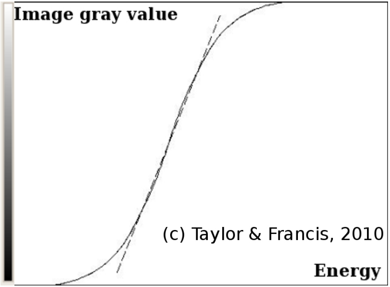


Figure: A general concept of a response curve. The x-axis gives the energy impacted on some sort of image detector. On the left side, there is not enough energy to evoke a response from the detector. On the right side, the energy flux on the detector is so high that it can no longer respond by a proportional gray value(or a similar signal). The gradient of the linear approximation in the dynamic range determines the $\gamma - \textit{value}$ of the detector.

Intensity Transform Function and Dynamic Range

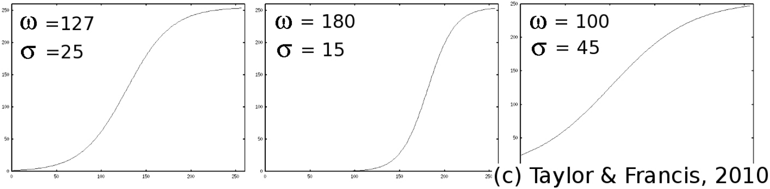


Figure: Three Sigmoid curves, defined on an 8 bit gray scale range $\rho \in \{0...255\}$. The parameters from Equation 3.2 were slightly varied. The impact of these modelled CTF curves will be demonstrated in Section 3.5.3.

Overview

Windowing

Tissue	HU
Air	-1024
Lung	-900...-200
Water	0
Blood	20...60
Liver	20...60
Bone	50...3072
Kidney	40...50
Cortical Bone	> 250

Table: Typical Hounsfield units of some materials and tissue types. (Data are from A. Oppelt(ed.):Imaging System for Medical Diagnostics, Wiley VCH,(2006).)

Windowing

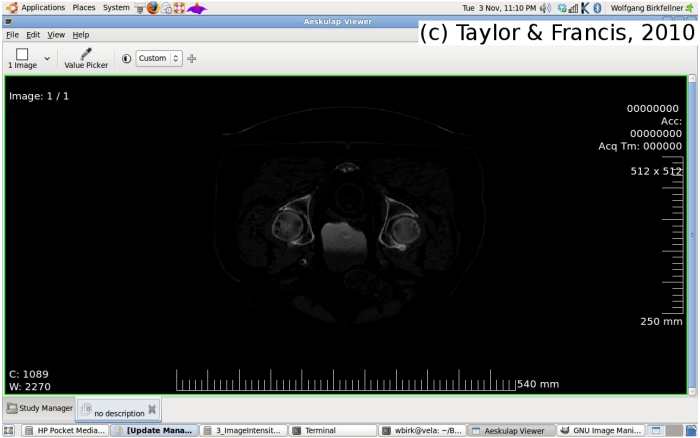


Figure: A screen-shot from the public domain DICOM viewer Aeskulap by A.Pipelka. Windowing is a standard feature here and is controlled by moving the cursor while pressing the mouse button.

Windowing

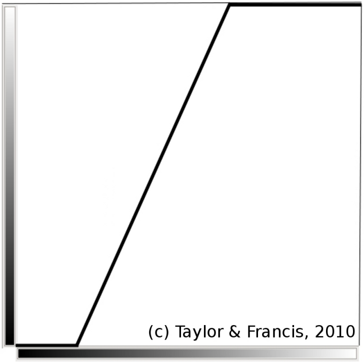


Figure: The general sharp of an ITF for windowing. The difference between the higher and lower intensity values on the abscissa at the location of the sharp kinks in the ITF gives the window width; the window center lies in the middle of this window.

Overview

Histograms and Histogram Operations

Figure: The effect of windowing a 12 bit CBCT-image. Two combinations of window center/window width are chosen, one giving optimum soft tissue contrast, the other showing details of bony structure. Interesting details are the liquid level of contrast agent in the bladder, which is of higher specific gravity than the urine, and a calcification of the right femoral artery(both marked by arrows in the first image). A ring artefact can also be seen in the bladder.

Histograms and Histogram Operations

Two important rules for designing a histograms bin width exist:

- **The histogram has to be complete and unambiguous;** for each gray value ρ there is one and only one bin to which it belongs.
- **The histogram bins should be of the same width;** this is, however, not always feasible, for instance if outliers are present. Therefore, the area of the column is the relevant value which represents the frequency of occurrence for a certain range of gray values, not its height. In image processing, however, bins of varying width are uncommon and should be avoided.

Histograms and Histogram Operations

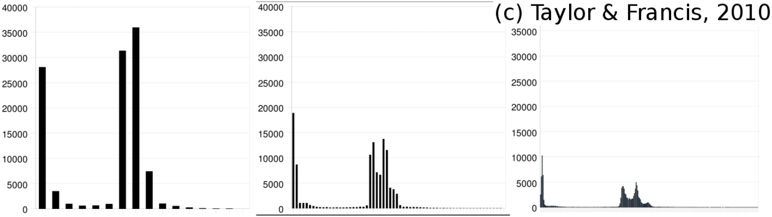


Figure: The histogram of the original abdomen CT-slice given in Figure 3.10, computed using 16 bin, 64 bins, and 256 bins(which is equivalent to the image depth).

Overview

A classical algorithm is **Floyd-Steinberg dithering**, but numerous other algorithms exist.

$$\frac{1}{16}\begin{bmatrix} & * & 7 \\ 3 & 5 & 1 \end{bmatrix}$$

Figure: The algorithm achieves dithering by diffusing the quantization error of a pixel to its neighboring pixels, according to the distribution(left); Example of a 24-bit RGB image dithered to 3-bit RGB using Floyd-Steinberg dithering(right)

Overview

Practical Lessons

Linear adjustment of image depth range

- First, we have to load the image again.
- Next, the minimum and maximum values of the image are determined. The result:

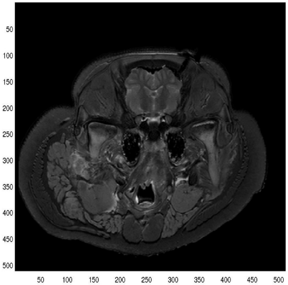
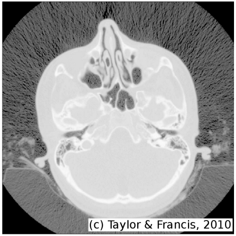


Figure: The output from LinearIntensityTransform3.m.

Practical Lessons

Improving visibility of low-contrast detail-taking the logarithm

- First,open a DICOM image from CT showing an axial slice;
- Next,transform the range of gray values from $\{min, \cdots, max\}$ to $\{1, \cdots, max - min + 1\}$ just to avoid the pole of log(0).
- the logarithm is taken and the result is scaled to 6 bit image depth and displayed. The result:



Modelling a general non-linear transfer function-the Sigmoid(cont')

- First,assign the working volume again, and load the image *ABD_CT.jpg* using *imread*;
- Next,a vector containing the values for $S(\rho)$ is defined and filled;the parameters *pomega* and *psigma* have to be defined as well.
- After calling *colormap*(*gray*), *image*(*transimage*) and *image*(*oimg*)show the transformed and the original image.

Additional Tasks:
Repeat the procedure for parameter pairs $\omega/\sigma = 180/15$ and $100/45$. Results are showing below. Try it!

Practical Lessons

Modelling a general non-linear transfer function-the Sigmoid

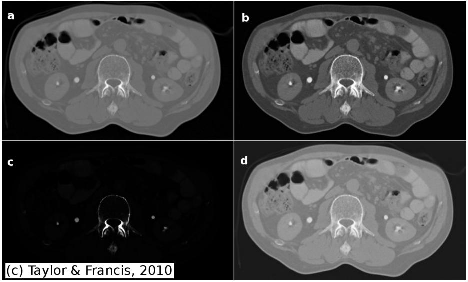


Figure: The impact of the three sigmoid functions $S(\sigma)$ from Fiture 3.3 on an 8-bit CT slice of the abdomen(upper left, denoted as **a**). The first function with $\omega = 127$ and $\sigma = 25$ (upper right, denoted as **b**). A sigmoid function with $\omega = 180$ and $\sigma = 15$(lower left, denoted as **c**). a wide and shallow sigmoid ($\omega = 100$ and $\sigma = 45$) gives a dull image(lower right, denoted as **d**).

Practical Lessons

Intensity Function

Windowing

Histograms

Dithering

Practical Lessons

Histograms and histogram operations

- First,allocate a vector *hist*16, which will be our histogram with 16 bins.
- Next,determine the minimum gray value of the image, which is the starting point of the first bin, and the bin width.
- Sort the gray values ρ into the histogram bins. The image has a width of 435 pixels and a height of 261 pixels;

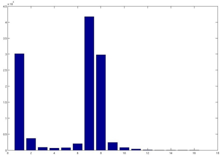


Figure: The output from *Histogram_3.m*, where a histogram of 16 bins is computed from the 8 bit image *ABD_CT.jpg*.

Summary

- Transformations in intensity space play an extremely important role in medical image processing and image display.
- Transformations can range from applying rather simple analytical function like taking the logarithm to more sophisticated models, such as : parametrized sigmoid curves,special windowing operations.
- The distribution of gray values is represented by a histogram.