Biometric Authentication

Lecture 3

Biometrics Technology: Image & Signal Processing

Outline

- Digital Image: Introduction
- Basic Processing Technologies:

  - Point (Pixel) Operations
  - Group (Neighborhood) Operations

Digital Image: Introduction

Digital Image Processing

- Brightness
- Contrast
- Noise reduction
- Edge enhancement
- Zooming
- Object trackers
- Object classification

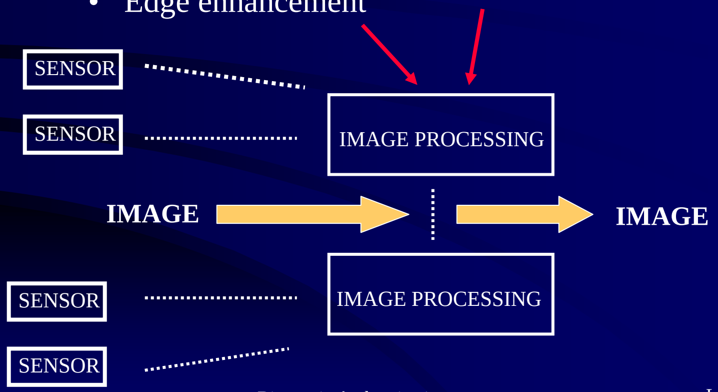
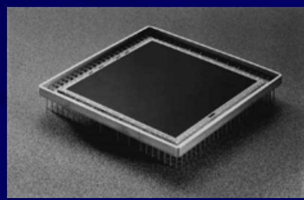


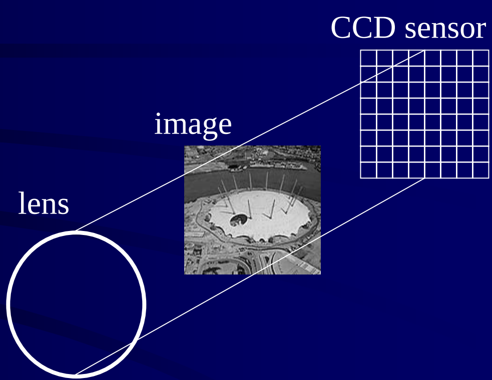
Image Acquisition

- Source of imagery
  - Charge-coupled device (CCD) sensor
- Rectangular array of detectors
- Measure brightness (intensity) and colour
- Intensity determined via sampling over region of pixel.



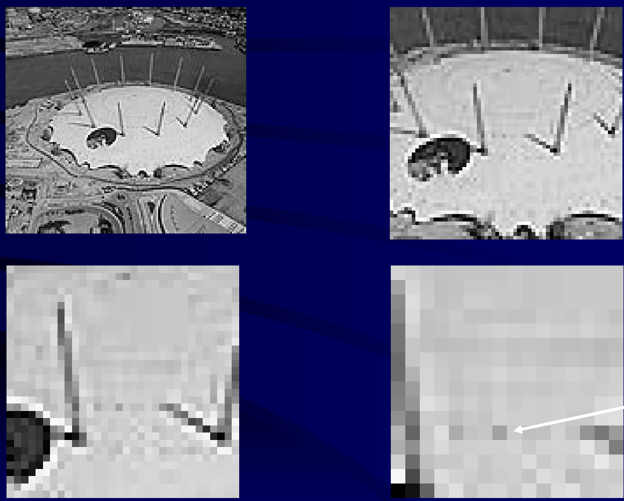
Digital Image Representation

- Optical image denoted by *A(x,y)*
- *x* and *y* are spatial co-ordinates
- *A(x,y)* is the brightness at position *(x,y)*



The points at which an image is sampled are known as *picture elements*, or *pixels.*

Digital Image Representation



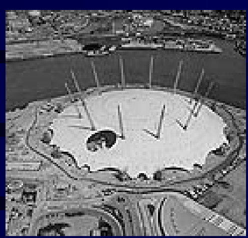
picture element (pixel)

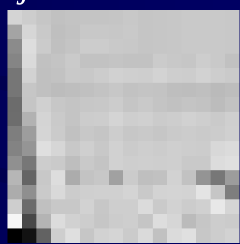
Digital Image Representation

$A(x,y)$ $A_{i,j}$

y j column

x i





row

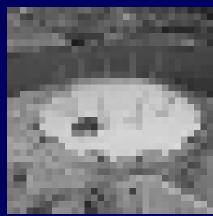
Continuous Discrete

- An image is a spatial presentation of an object – *Matrix representing quantized intensity values*.

Image Resolution

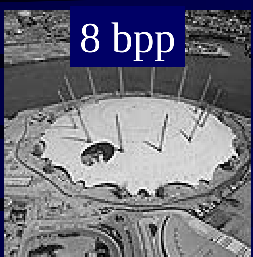
- Image resolution: Measure of image quality (No. of pixels, $M \times N$)
  - 1280 x 960 (digital camera)
  - 512 x 512 (video camera)
  - 256 x 256 (reasonable processing quality)
- Dynamic range: Measure of the range of brightness values
  - 1 bit (binary image)
  - 8 bits (grey image: 0 for black, 255 for white)
  - 12 bits (medical imagery)
  - 16 bits (Astronomical imagery)
  - 24 bits (colour image)

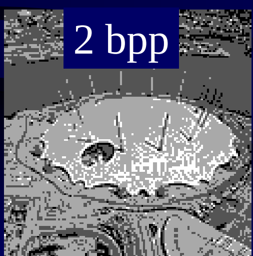
High



Low

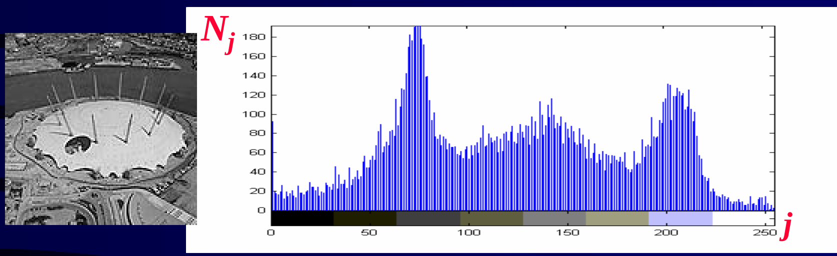
Gray-Level Quantisation





- For black and white images, a pixel is a single value *integer* or *floating point.*
- For display, normally 8 bits per pixel (bpp) is used.
- The human eye cannot resolve to this accuracy. 32 gray levels are usually sufficient (5 bpp).
- At 4 bpp and below, "false contouring" can become apparent.

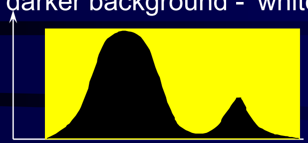
Image Histograms



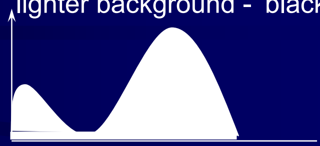
- Plot of N_j versus j: Shows the distribution of image pixels in terms of their gray levels.
- Gray levels $j=0,1,\ldots,255$
- N_j= number of pixels in image with gray level j

Bimodal Histograms

Light object(s) against a darker background - 'white hot'

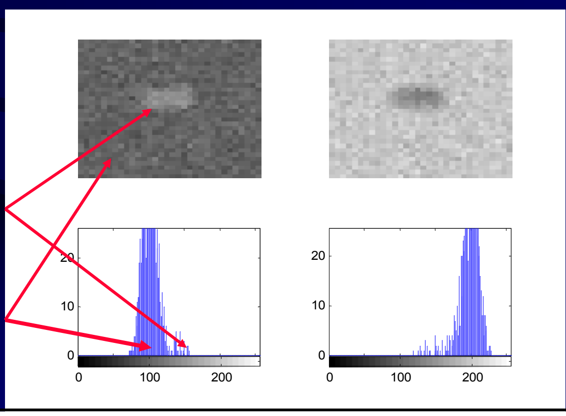


Dark object(s) against a lighter background - 'black hot'



Bright object

Dark background



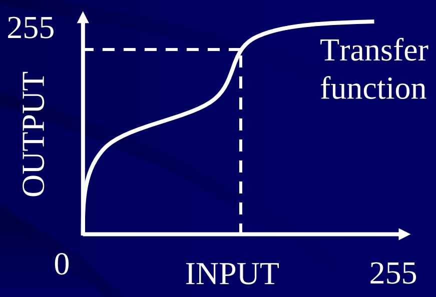
Point (Pixel) Operations

Point (Pixel) Operation

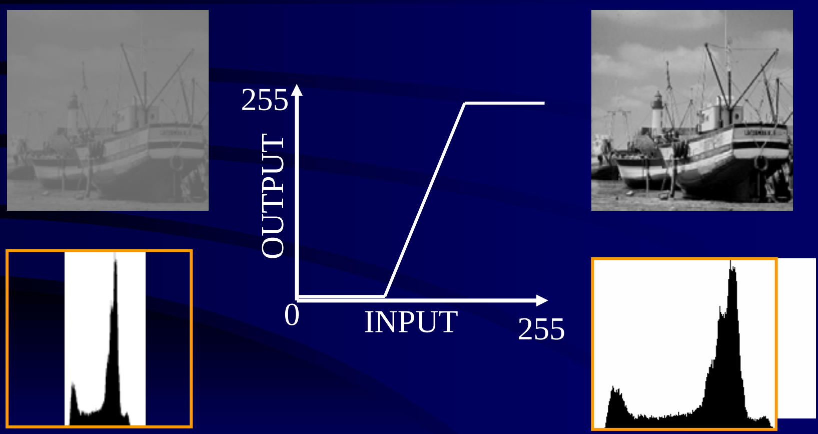
- Point operation: A function is applied to every pixel in an image, which operates only on the pixel's current value.
- Thresholding - A mask may be created by setting a pixel value to 1 or 0 depending upon if the current value is above or below a certain threshold value.

Input pixel value, I, mapped to output pixel value, O, via transfer function T.

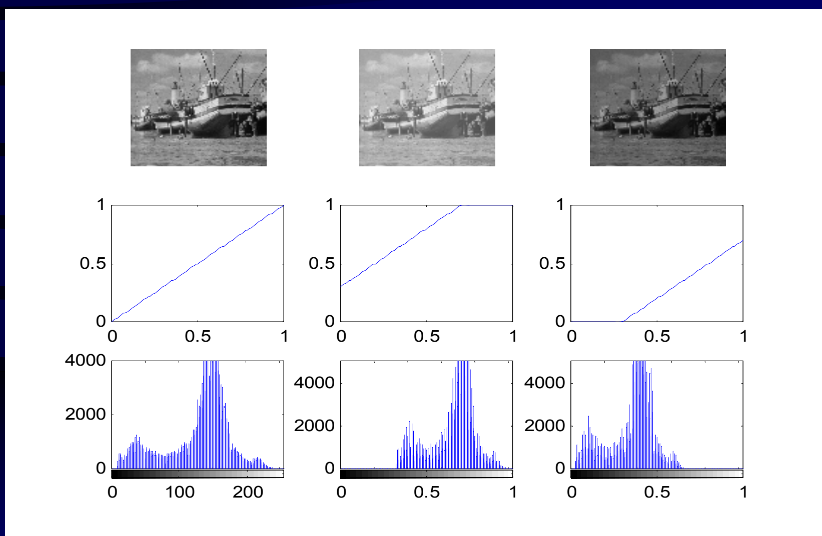
$$O=T(I)$$



Contrast Enhancement: Linear Stretching



Brightness

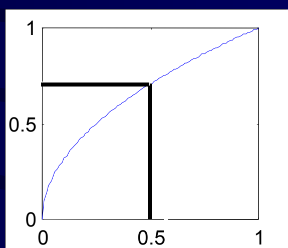


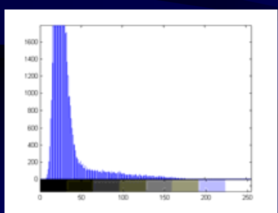
Contrast Enhancement: Power Law Function

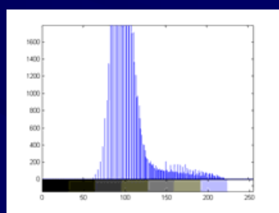
$$O = I^{\gamma}$$

- $\gamma < 1$ to enhance contrast in dark regions
- $\gamma > 1$ to enhance contrast in bright regions.

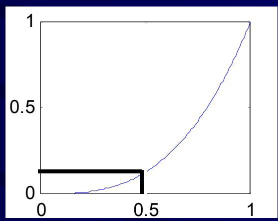
Contrast Enhancement: Power Law Function ($\gamma = 0.5$)

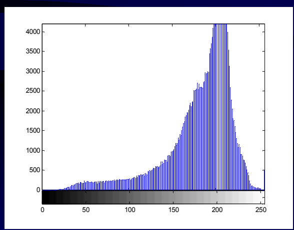


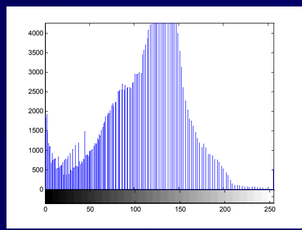




Contrast Enhancement: Power Law Function (γ = 3.0)







Contrast Enhancement: Power Law Function

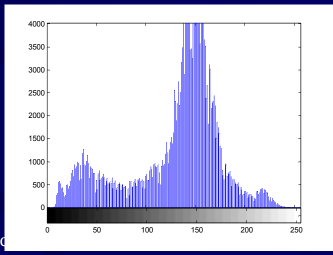
- Look-up Table
  - Transfer function implemented as a look-up table (LUT).
  - Implemented in hardware or software.

γ=2

I	*O*
0	0
0.10	0.01
0.20	0.04
0.30	0.03
0.40	0.16
0.50	0.25
0.60	0.36
0.70	0.49
0.80	0.64
0.90	0.81
1.00	1.00

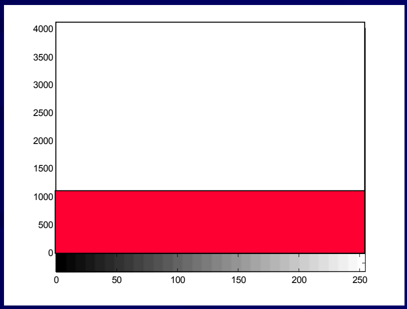
Contrast Enhancement: Histogram Equalisation

- Image histograms consisting of peaks and low plains.
- Peaks = many pixels concentrated in a few grey levels
- Plains = small number of pixels distributed over a wider range of grey levels



Histogram Equalisation

- Expand pixels in peaks over a wider range of gray-levels.
- “Squeeze” low plains pixels into a narrower range of gray levels.
- **<u>Flat</u>** histogram.



Contrast Enhancement: Comparison

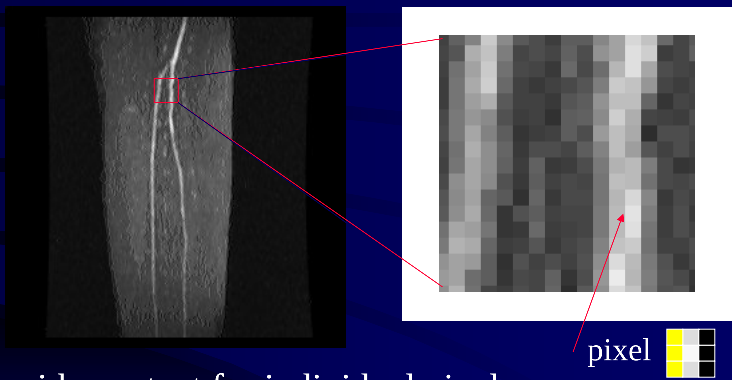
Original

$\gamma > 1$

Histogram equalisation

Group (Neighborhood) Operations

Why are Neighbourhoods Important?



- Provide context for individual pixels.
- Relationships between neighbours determine image features.

Neighbourhood Operations

Noise Reduction

Edge Enhancement

Zooming

Convolution

- Consists of filtering an image *A* using a filter (mask) *B*.
- Mask is a small image whose pixel values are called weights.
- Weights modify relationships between pixels.

Filter, mask or template **B** | Input image **A** | Convolved Image **C**

$$\begin{array}{|c|c|}\hline B_{1,1} & B_{1,2} \\ \hline B_{2,1} & B_{2,2} \\ \hline \end{array} \; . \quad \begin{array}{|c|c|c|c|}\hline A_{1,1} & A_{1,2} & A_{1,3} & A_{1,4} \\ \hline A_{2,1} & A_{2,2} & A_{2,3} & A_{2,4} \\ \hline A_{3,1} & A_{3,2} & A_{3,3} & A_{3,4} \\ \hline A_{4,1} & A_{4,2} & A_{4,3} & A_{4,4} \\ \hline \end{array} = \begin{array}{|c|c|c|}\hline C_{1,1} & C_{1,2} & C_{1,3} \\ \hline C_{2,1} & C_{2,2} & C_{2,3} \\ \hline C_{3,1} & C_{3,2} & C_{3,3} \\ \hline \end{array}$$

2×2 | 4×4 | 3×3

Convolution

$$\begin{array}{|c|c|c|c|}\hline B_{1,1} & B_{1,2} & A_{1,3} & A_{1,4} \\ \hline B_{2,1} & B_{2,2} & A_{2,3} & A_{2,4} \\ \hline A_{3,1} & A_{3,2} & A_{3,3} & A_{3,4} \\ \hline A_{4,1} & A_{4,2} & A_{4,3} & A_{4,4} \\ \hline \end{array} \qquad \begin{array}{|c|c|}\hline A_{1,1}\times B_{1,1} & A_{1,2}\times B_{1,2} \\ \hline A_{2,1}\times B_{2,1} & A_{2,2}\times B_{2,2} \\ \hline \end{array}$$

$$C_{1,1} = \boxed{A_{1,1}\times B_{1,1}} + \boxed{A_{1,2}\times B_{1,2}} + \boxed{A_{2,1}\times B_{2,1}} + \boxed{A_{2,2}\times B_{2,2}}$$

Convolution

$A_{1,1}$	$A_{1,2}$	$B_{1,1}$	$B_{1,2}$
$A_{2,1}$	$A_{2,2}$	$B_{2,1}$	$B_{2,2}$
$A_{3,1}$	$A_{3,2}$	$A_{3,3}$	$A_{3,4}$
$A_{4,1}$	$A_{4,2}$	$A_{4,3}$	$A_{4,4}$

$A_{1,3}\times B_{1,1}$	$A_{1,4}\times B_{1,2}$
$A_{2,3}\times B_{2,1}$	$A_{2,4}\times B_{2,2}$

$$C_{1,3}= \boxed{A_{1,3}\times B_{1,1}} + \boxed{A_{1,4}\times B_{1,2}} + \boxed{A_{2,3}\times B_{2,1}} + \boxed{A_{2,4}\times B_{2,2}}$$

Convolution

$A_{1,1}$	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$
$B_{1,1}$	$B_{1,2}$	$A_{2,3}$	$A_{2,4}$
$B_{2,1}$	$B_{2,2}$	$A_{3,3}$	$A_{3,4}$
$A_{4,1}$	$A_{4,2}$	$A_{4,3}$	$A_{4,4}$

$A_{2,1}\times B_{1,1}$	$A_{2,2}\times B_{1,2}$
$A_{3,1}\times B_{2,1}$	$A_{3,2}\times B_{2,2}$

$$C_{2,1}= \boxed{A_{2,1}\times B_{1,1}} + \boxed{A_{2,2}\times B_{1,2}} + \boxed{A_{3,1}\times B_{2,1}} + \boxed{A_{3,2}\times B_{2,2}}$$

Mathematical Notation

$$\mathbf{C_{1,1}} = \boxed{A_{1,1} \times B_{1,1}} + \boxed{A_{1,2} \times B_{1,2}} + \boxed{A_{2,1} \times B_{2,1}} + \boxed{A_{2,2} \times B_{2,2}}$$

$$B = M \times N$$

$$C_{k,l} = \sum_{i=k}^{k+M-1} \sum_{j=l}^{l+N-1} A_{i,j} \times B_{i-k+1,j-l+1}$$

$$\sum_{i=1}^{2} i = 1 + 2$$

$$\sum_{i=1}^{2} A_i = A_1 + A_2$$

$$\sum_{i=1}^{2} \sum_{j=1}^{2} A_{i,j} = \sum_{i=1}^{2} \left(A_{i,1} + A_{i,2}\right) = A_{1,1} + A_{1,2} + A_{2,1} + A_{2,2}$$

Summations

$$C_{k,l} = \sum_{i=k}^{k+M-1} \sum_{j=l}^{l+N-1} A_{i,j} \times B_{i-k+1,j-l+1}$$

$$C_{1,1} = \sum_{i=1}^{1+2-1} \sum_{j=1}^{1+2-1} A_{i,j} \times B_{i-1+1,j-1+1}$$

$$= \sum_{i=1}^{2} \sum_{j=1}^{2} A_{i,j} \times B_{i,j}$$

$$= \sum_{i=1}^{2} A_{i,1} \times B_{i,1} + A_{i,2} \times B_{i,2}$$

$$= A_{1,1} \times B_{1,1} + A_{1,2} \times B_{1,2} + A_{2,1} \times B_{2,1} + A_{2,2} \times B_{2,2}$$

$M=N=2$
$k=l=1$

Convolution

Filter, mask or template

B

-1	2
-1	2

2×2

Input image

A

4	4	7	9
4	3	8	9
3	5	9	9
3	6	10	9

4×4

=

Convolved Image

C

6	23	21
9	26	19
16	27	17

3×3

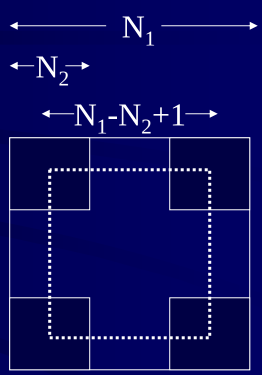
Convolution Size

Image size = $M_1 \times N_1$

Mask size = $M_2 \times N_2$

Convolution size = $(M_1 - M_2 + 1) \times (N_1 - N_2 + 1)$

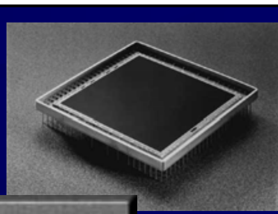
Typical Mask sizes = 3×3, 5 ×5, 7×7, 9 ×9, 11×11



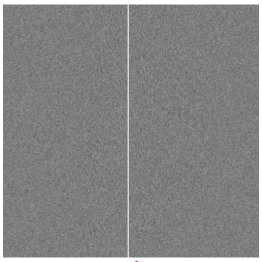
What is the convolved image size for a 128 ×128 image and 7 × 7 mask?

Noise

- Source of noise = CCD chip.
- Electronic signal fluctuations in detector.
- Caused by thermal energy.
- Worse for infra-red sensors.



image

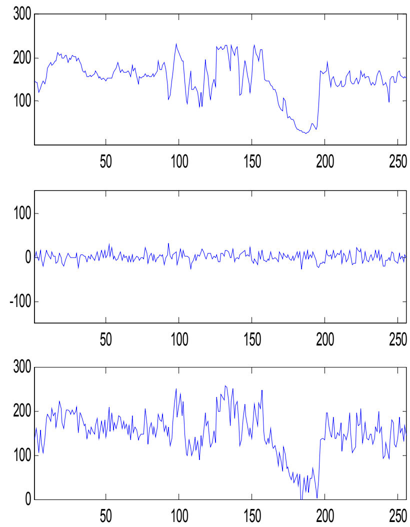


noise

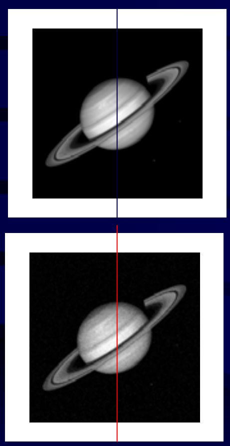
'grainy' image

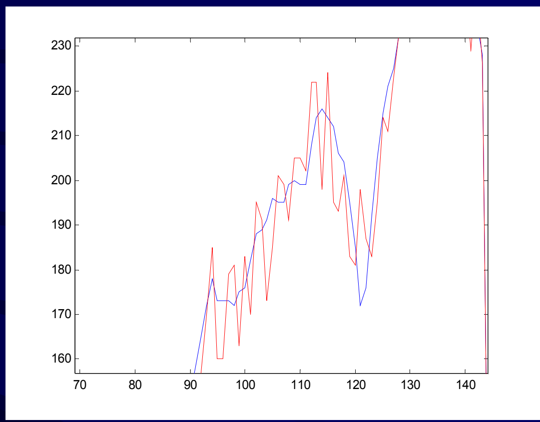
Noise

- Plot of image brightness.
- Vertical slice through image.
- Noise is additive.
- Noise fluctuations are rapid, i.e, high frequency.



Noise Reduction

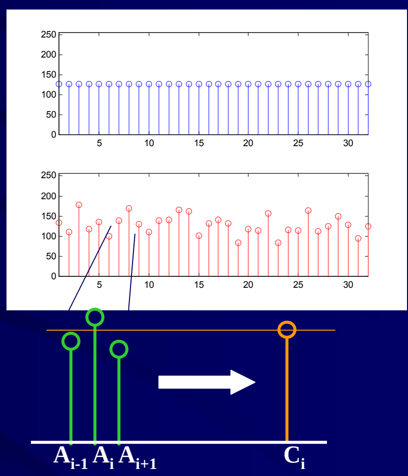




- Noise varies above and below uncorrupted image.

Noise Reduction-1st principles

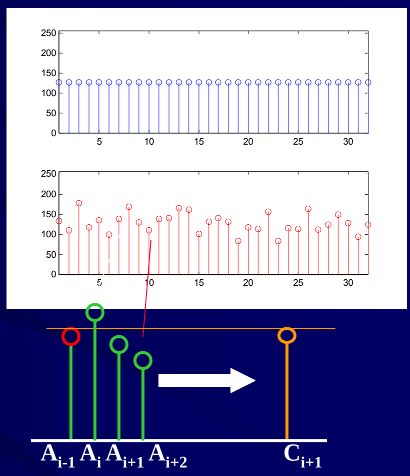
- How do we reduce noise?
- Consider a uniform 1-d image A and add noise.
- Focus on a pixel neighbourhood.
- Central pixel has been increased and neighbouring pixels have decreased.



Noise Reduction-1st principles

- Averaging 'smoothes' the noise fluctuations.
- Consider the next pixel A_{i+1}
- Repeat for remainder of pixels.

$$C_{i+1} = \frac{A_i + A_{i+1} + A_{i+2}}{3}$$



Noise Reduction-Neighborhood Operations

- All pixels can be averaged by convolving *1-d* image *A* with mask **B** to give enhanced image *C*.
- Weights of *B* must equal one when added together.

$$\mathbf{C} = \mathbf{A} * \mathbf{B}$$
$$\mathbf{B} = [B_1 \quad B_2 \quad B_3]$$
$$C_i = A_{i-1} \times B_1 + A_i \times B_2 + A_{i+1} \times B_3$$
$$B = \frac{1}{3}[1 \quad 1 \quad 1]$$
$$C_i = \frac{A_{i-1} + A_i + A_{i+1}}{3}$$

$$\mathbf{C} = \mathbf{A} * \mathbf{B}$$
$$\mathbf{B} = \frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

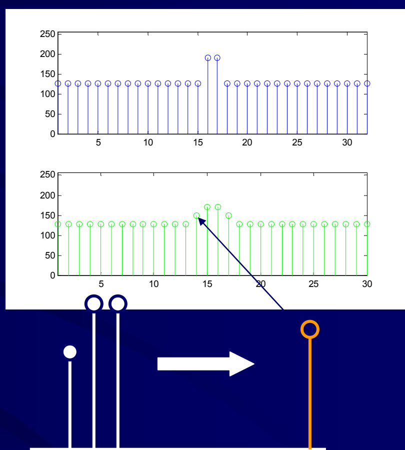
- Extend to two dimensions.

Noise Reduction

- Technique relies on high frequency noise fluctuations being ‘blocked’ by filter. Hence, low-pass filter.
- Fine detail in image may also be smoothed.
- Balance between keeping image fine detail and reducing noise.
- Example:
  - Saturn image coarse detail
  - Boat image contains fine detail
  - Noise reduced but fine detail also smoothed

Noise Reduction

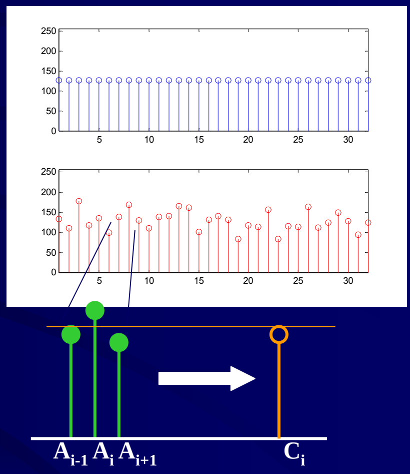
- Consider a uniform 1-d image A with a step function.
- Step function corresponds to fine image detail such as an edge.
- Low-pass filter ‘blurs’ the edge.



Noise Reduction-1st principles

- How do we reduce noise without averaging?
- Consider a uniform 1-d image A and add noise.
- Focus on a pixel neighbourhood.
- Non-linear operator?

Median filter!



Noise Reduction-Neighborhood Operations

- All pixels can be replaced by neighbourhood median by convolving 1-d image A with median filter B to give enhanced image C.

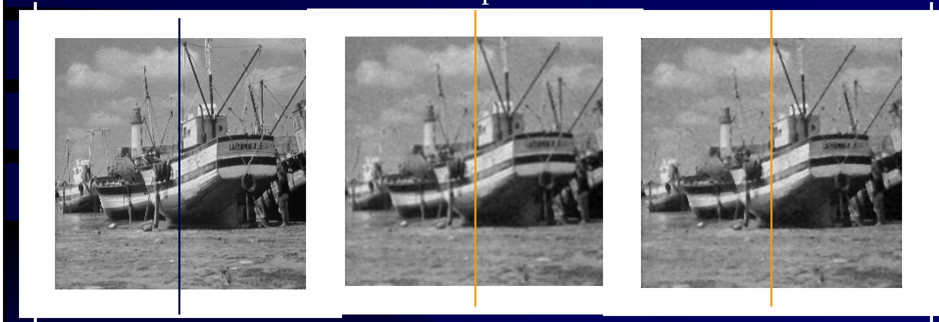
$$\mathbf{C} = \mathbf{A} * \mathbf{B}$$
$$\mathbf{B} = \begin{bmatrix} B_1 & B_2 & B_3 \end{bmatrix}$$
$$C_i = \text{median}\{A_{i-1} \times B_1, A_i \times B_2, A_{i+1} \times B_3\}$$
$$\mathbf{B} = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$$
$$C_i = \text{median}\{A_{i-1}, A_i, A_{i+1}\}$$

- Extend to two dimensions.

$$C_{k,l} = \underset{i=k:k+M-1,\, j=l:l+N-1}{\text{median}} \{A_{i,j} \times B_{i-k+1,\, j-l+1}\}$$
$$B_{i,j} = 1 \text{ for all } i,j$$

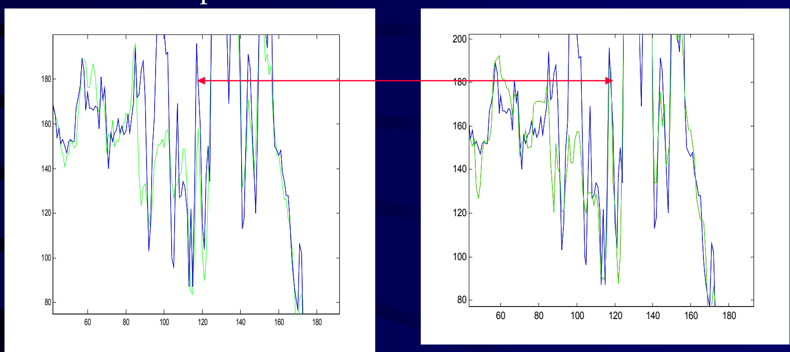
Noise reduction

Original | Low-pass | Median



Noise reduction

Low-pass | Median



- Low-pass: fine detail smoothed by averaging
- Median: fine detail passed by filter

Filter Operations

1 Low-Pass Filter

- Class: Image Enhancement/Restoration
- Implementation: Pixel group process and smooth an image

$$\begin{matrix}1&1&1\\1&1&1\\1&1&1\end{matrix} \;/9 \qquad \begin{matrix}1&1&1\\1&2&1\\1&1&1\end{matrix} \;/10 \qquad \begin{matrix}1&2&1\\2&4&2\\1&2&1\end{matrix} \;/16$$

Filter Operations

2 High-Pass Filter

- Implementation: Pixel group process and sharpen an image

$$\begin{matrix}-1&-1&-1\\-1&9&-1\\-1&-1&-1\end{matrix} \qquad \begin{matrix}0&-1&0\\-1&5&-1\\0&-1&0\end{matrix} \qquad \begin{matrix}1&-2&1\\-2&5&-2\\1&-2&1\end{matrix}$$

3 Sobel Edge Enhancement

- Implementation: Edge extraction

$$\begin{matrix}-1&0&1\\-2&0&2\\-1&0&1\end{matrix} \qquad \begin{matrix}-1&-2&-1\\0&0&0\\1&2&1\end{matrix}$$

Vertical mask Horizontal mask

Filter Operations

4 Shift and Difference Edge Enhancement

- Implementation: Vertical, Horizontal and Diagonal Edge extraction

Vertical	Horizontal	Diagonal
$\begin{matrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{matrix}$	$\begin{matrix} 0 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{matrix}$	$\begin{matrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{matrix}$

5 Laplacian Edge Enhancement

- Implementation: All Edge extraction

$$\begin{matrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{matrix} \qquad \begin{matrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{matrix} \qquad \begin{matrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{matrix}$$

Questions?

1. **There are two operations (point and neighborhood) introduced by this lecture. How to use these two operations in our biometrics system?**

2. **Signal/image preprocessing is an important stage in biometrics system. Please list what problems we should solve during this stage.**

3. **There are some examples of filter operations. Please point out the difference of Low-pass filters, High-pass filters and Edge enhancement filters. Notice that the "0"-Sum mask for Edge enhancement filters and "1"-Sun for others.**

So much for today!

Thank you !!!