Image Analysis

(SE3IA11 + SEMIP12)

Lectured by

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Room 145 (HW) and Room 123 (JMF)

the SSE Building

Reference books

- Rafael Gonzalez & Richard Woods, ***Digital Image Processing***, 2nd edition, Prentice Hall, 2002
- S G Hoggar, ***Mathematics of Digital Images – Creation, Compression, Restoration, Recognition***, Cambridge Univ. Press, 2006
- Anil K. Jain, ***Fundamentals of Digital Image Processing***, Prentice Hall, 1989
- Milan Sonka, Vaclav Hlavac, and Roger Boyle, ***Image Processing, Analysis, and Machine Vision***, Thomson Learning, 2007

Recommended Journals

- *IEEE Transaction on* ***Image Processing***
- ***Image and Vision Computing***
- *IEEE Transaction on* ***Pattern Analysis and Machine Intelligence*** *(PAMI)*
- Many conference proceedings, *e.g.*
  - International Conference of Image Processing (ICIP)
  - International Conference of Pattern Recognition (ICPR)
  - International Conference of Computer Vision (ICCV)
  - Computer Vision and Pattern Recognition (CVPR)
  - British Machine Vision Conference (BMVC)
  - More ……

Arrangements for the module

- This is a 10 credit module running through the autumn term. Two lectures a week.
  - 14:00-16:00 Fridays for 10 weeks (HARB164)
  - Week 3 is used for a tutorial in a lab (SSE G21)
  - Week 11 is for a demonstration in a lab (SSE G21)
- Two pieces of coursework associated with lab practicals (unsupervised)
  - Assignment 1: image enhancement (15% assessment)
  - Assignment 2: image compression (15% assessment)
- One 2-hour written examination in May/June 2016. It counts 70% of the final assessment.

Contents covered in this module

- Fundamentals of digital images
- Image enhancement
- Colour image processing
- Image compression
- Mathematical morphology in image processing
- Image segmentation

Detailed scheduling

Week	Topic	Lecturer
Week 1 (2nd October)	Fundamentals of Image Analysis	HW
Week 2 (9th October)	Image Enhancement (Spatial)	JMF
Week 3 (16th October)	Tutorial (MatLab+OpenCV)	HW
Week 4 (23th October)	Image Enhancement (Frequency)	JMF
Week 5 (30st October)	Colour Image Processing	HW
Week 7 (13th November)	Image Compression (IC)	JMF
Week 8 (20th November)	IC2 / Symbolic Feature Extraction	JMF
Week 9 (27th November)	Morphological Image Processing	HW
Week 10 (4th December)	Image Segmentation	HW
Week 11 (11th December)	Compression coursework assessment	HW&JMF

Digital image analysis

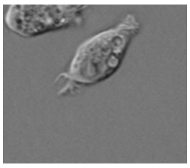
- Questions to be answered in this module
  - What is digital image?
  - How is a digital image formed mathematically?
  - Are there any applications where image analysis is required?
  - How to make the applications feasible?
    - Various techniques and processes

Applications of image analysis (1)

- Medical and biomedical images

(a) Gastric body from endoscope

(b) Hip joints from X-ray



(c) Cells from microscope

Applications of image analysis (2)

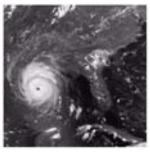
- Further medical images

(a) MRI of human spine

(b) Ultrasound image of a baby

Applications of image analysis (3)

- Remotely sensed data in climate and environment research – observation



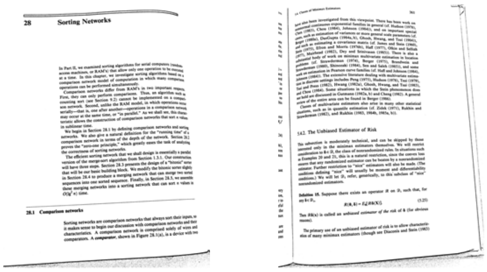
(a) Multispectral image of hurricane (from GEO Satellite)

(b) SAR image: surface of Venus (from Magellan probe)

(c) LIDAR data (from airborne laser scanning)

Applications of image analysis (4)

- Image-based document analysis



Applications of image analysis (5)

- Security (CCTV): visual surveillance
- Webcam application: looking after elders through mobile phones
- London congestion control: automatic number plate recognition (ANPR)
- Biometrics: face images, finger prints, iris images,…
- Information retrieve in the Internet: image based information search (Google Goggles).
- The *Google Book Search* project unveiled in late 2004 aims to make all the world's books discoverable online.
- And more ……

Typical processes in image analysis

(from perception to cognition)

- Image acquisition
- Image enhancement and restoration
- Image compression
- Morphological processing
- Image segmentation and description
- Recognition: understanding and interpretation (intelligent?)

A computer imaging system

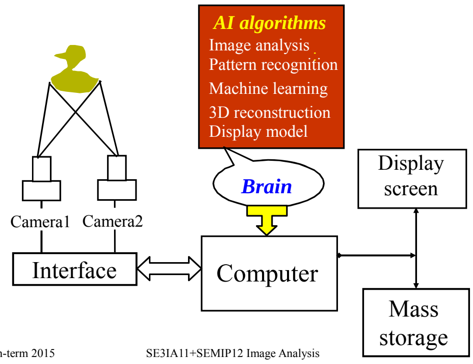


Image acquisition: lighting (electromagnetic radiation – EMR)

- "Light" in imaging covers a part of the electromagnetic spectrum beyond the visible spectrum (wavelength 380-760 nm).
- Light has two forms of energy: electricity and magnetism which are transmitted together as EMR in the speed of 2.998×10^8m/s.
- The electromagnetic spectrum can be expressed in terms of wavelength, frequency (or energy), and speed as

$\lambda = \frac{c}{v}$ and energy $E = hv$ with h a constant.

where λ is wavelength, v frequency, and c speed.

The electromagnetic spectrum

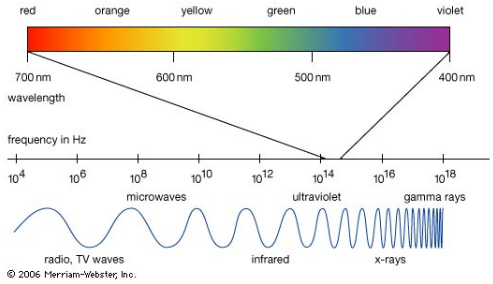


Image acquisition: sensors (1)

- Imaging is a process in which the reflected energy from illuminated scenes is received (or collected) by sensing elements or materials, called sensors.
- Four components: light source, scene, sensors, and lens – optical systems.
- Sensors must be responsive to light sources, *e.g.* X-ray, infrared, visible lights, etc. by using different sensing materials (*e.g.* different CCD or CMOS).
- Sensing: transform incoming illumination energy (reflected from scene) into a voltage by sensors, from which the output voltage is digitised to generate a value of a pixel in a digital image.

Image acquisition: sensors (2)

- Three principal sensor arrangements
  - *Single sensor*: sensor moving, *e.g.* raster scanning
  - *Line sensor*: sensor strip in linear motion
  - *Sensor arrays*: popularly used in normal digital cameras and cam-recorders.
- Outputs of all the above different sensors could be arranged to a 2D array reflecting illumination energy of a scene.

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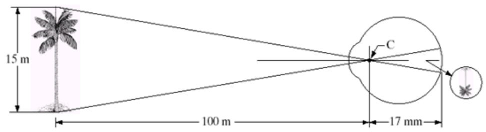
Image acquisition: optical systems

- An optical system (lens) plays the role to refract an observed scene onto an imaging plane (i.e. a focal plane in the pin-hole model).



C is the optical centre of the lens.

PSF and MTF in an optical system

- PSF: the *point spread function* indicates an optical system response to an impulse $\delta(x, y)$.
  - All physical optical systems blur (spread) a point of light to some degree. After an optical system, $\delta(x, y)$ becomes to $h(x,\alpha, y,\beta) = H[\delta(x-\alpha, y-\beta)]$, mathematically called convolution, where α and β are parameters related with the optical system.
- MTF: the *modulation transfer function* is defined as

$$MTF(f_s) = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

where I_{max} and I_{min} are maximum and minimum grey values of pixels in an image, respectively. *MTF* is a function of spatial frequency f_s. It is affected by the arrangement of sensor arrays.

Representation of digital images

- A digital image is normally represented by a two-dimensional (2D) array, *e.g. f(x,y)*, where *x*=1,2…M and *y*=1,2…N, representing the size of the image.
- Each element in the array is a real number, called a **pixel** and represented by a finite number of bits.
- A matrix denotes a digital image in the formal mathematic term.

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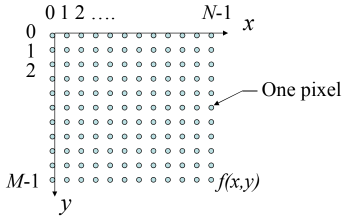
Digital image: matrix expression

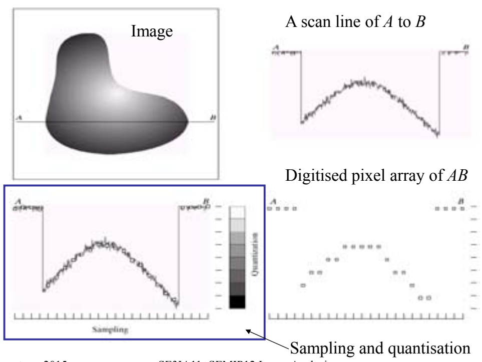


$$f(x,y)=\begin{bmatrix} f(0,0) & f(0,1) & \dots & f(0,N-1) \\ f(1,0) & f(1,1) & \dots & f(1,N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \dots & f(M-1,N-1) \end{bmatrix}$$

Image sampling and quantisation (1)

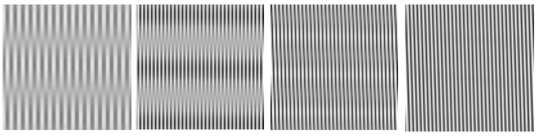
- Image sampling deals with issues of how many pixels are used to represent a scene.
  - Digitising the coordinate values: the Nyquist sampling theorem is applied.
  - The Nyquist states that the minimum sampling frequency is twice as high as the signal frequency.
- Image quantisation regards issues of how many bits used for one pixel.
  - Digitising the amplitude values of illumination energy: the visual quality should be satisfied.

Image sampling and quantisation (2)



Example of image sampling (1)

- Sampling black and white bars with 100 lines/inch.
  - (a) 100 dpi (0.5 Nyquist-Shannon sampling rate)
  - (b) 200 dpi (with Nyquist-Shannon sampling rate)
  - (c) 300 dpi (1.5 Nyquist-Shannon sampling rate)
  - (d) 600 dpi (3 Nyquist-Shannon sampling rate)
  - where dpi stands for "dots per inch".



(a) (b) (c) (d)

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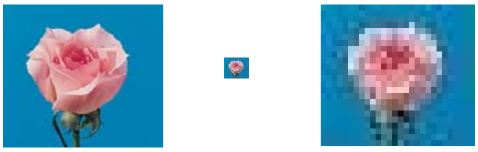
Example of image sampling (2)

- Pink rose in colours: details are lost in (c).
  - (a) 599×812×3 uint8
  - (b) 82×111×3 uint8
  - (c) The image in (b) re-sampled into 599×812.



(a) (b) (c)

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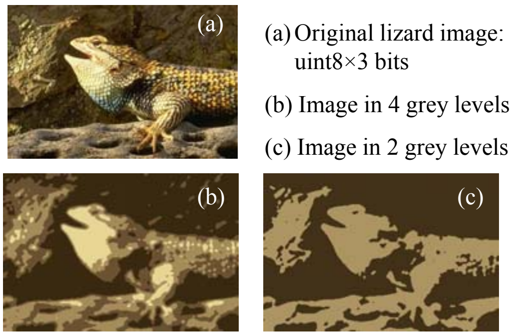
Example of image quantisation



(a) Original lizard image: uint8×3 bits

(b) Image in 4 grey levels

(c) Image in 2 grey levels

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Image resizing

- Shrinking digital images: operation of undersampling, *e.g.* 512×512 ⇨ 256×256
- Enlarge digital images: operation of oversampling, *e.g.* 256×256 ⇨ 512×512
- Two main steps in the operations
  - Creation of new pixel locations
  - Assignment of grey levels to those new locations
- Techniques used in the image resizing operation
  - Nearest neighbour interpolation (NNI)
  - Bilinear interpolation (BLI)

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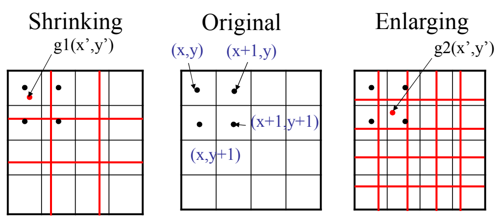
Image resizing: interpolation (NNI)



- For NNI: g1(x',y')=g(x,y); g2(x',y')=g(x+1,y+1)
- How about g1 and g2 based on the BLI algorithm?

http://www.cambridgeincolour.com/tutorials/image-interpolation.htm

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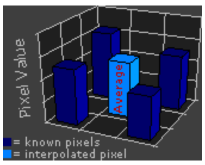
Image resizing: interpolation (BLI)



- Bilinear interpolation considers the closest 2×2 neighbourhood of known pixel values surrounding the unknown pixel.
- It takes a weighted average of these 4 pixels to arrive at its final interpolated value.
- This algorithm results in much smoother looking images than NNI.

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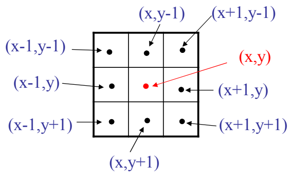
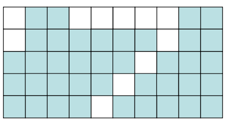
Relationships between pixels (1)

- Neighbours of a pixel $p(x,y)$
  - 4-neighbours $N_4(p)$: $(x-1,y)$, $(x+1,y)$, $(x,y-1)$, $(x,y+1)$
  - Four diagonal neighbours $N_D(p)$: $(x-1,y-1)$, $(x-1,y+1)$, $(x+1,y-1)$, $(x+1,y+1)$



Relationships between pixels (2)

- Regions and boundaries: binary images have two sets {1} and {0}
  - *Connectivity*: two pixels are neighboured, but they are connected only if they both belong to set {1} or set {0}.
  - *Connected components*: for any pixel p in set S, the set of pixels are connected to p in S is called a connected component in S.



$S\{1\}$: blue

$S\{0\}$: white

Relationships between pixels (3)

- Distance between pixels $p(x_1,y_1)$ and $q(x_2,y_2)$
  - The Euclidean distance

$$D_e = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

  - The D_4 distance: $D_4 = |x_1 - x_2| + |y_1 - y_2|$
  - The D_8 distance: $D_8 = \max(|x_1 - x_2|, |y_1 - y_2|)$

- Image operations on a pixel basis
  - Each pixel represents an element in a matrix.
  - Image operations follow operations among matrices.

Image quality evaluation

- Two types of criteria for image evaluation: subjective and quantitative.
- Quantitative evaluation of image *f(x,y)*:
  - A reference image *f'(x,y)* is needed.
  - The average mean square error is used for the evaluation as

$$\sigma^2 = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left|f(x,y) - f'(x,y)\right|^2$$

- Image fidelity criteria are useful for
  - Measuring image quality
  - Rating the performance of a processing techniques.

Questions for further thinking

- How to express a digital image mathematically ?
- Issues of digital image visualisation (sampling and quantisation)
- Based on the concept of image resizing, work out how to deal with image rotation (matrix rotation) and shape distortion.
- Image quality evaluation: try to think about more efficient measures for the purpose. Do we need benchmarks for the purpose? If so, how to establish the benchmarks (with assumptions)?

End of the first two lectures

- Summary of what you have learned in the two lectures.
- Revision on matrix operations