National Exams | 04-Bio-B4 — Digital Image Processing | December, 2015

Final Examination

Exam Notes

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit the answer paper with a clear statement of any assumptions made.
2. This is an OPEN BOOK EXAM. Any paper notes or textbooks are permitted.
3. **No** calculator or computer or any sort is permitted.
4. This exam contains SIX (6) questions, however FIVE (5) questions constitute a complete exam paper. The first five questions as they appear in the answer book will be marked.
5. Each question is of equal value.
6. The clarity and organization of the answers are important.
7. The exam is three hours long.

1. **Basic Definitions**

   For each of the following concepts, give a brief definition (2-4 sentences) and a description of where the concept is used or applied, in practice:

   (a) Image Watermarking

   (b) Image Downsampling

   (c) The CIE Colour Spaces (such as CIELab)

   (d) The two-dimensional Fast Fourier Transform (FFT)

   (e) Robust Image Features, such as SIFT or SURF

   (f) The Gabor Transform

   (g) The family of overcomplete wavelet transforms (such as dual-tree, complex, undecimated etc.)

2. **Image Filtering**

   (a) What do FIR and IIR refer to? Why are FIR filters much more common in the filtering of two dimensional images?

   (b) An image filter could be implemented via 2D convolution. An image $f(m,n)$ of size $M_1 \times N_1$ is convolved with a convolution kernel $h(m,n)$ of size $M_2 \times N_2$ to produce a new resulting image $g(m,n)$. Depending on how the convolution is implemented, g could be one of three different sizes. Specify these sizes.

   (c) An image filter could be implemented using an FFT:

      i. Using mathematical notation, give an example of using an FFT to implement a *separable* 2D filter.

      ii. Using mathematical notation, give an example of using an FFT to implement a *non-separable* 2D filter.

   (d) 2D median filters are very popular for image noise reduction:

      i. What makes the median filter attractive as an image filter?

      ii. Prove or demonstrate convincingly that the median filter is *nonlinear*.

   (e) Image filtering can be undertaken in a transformed domain, such as a wavelet transform. Briefly describe the filtering strategy of wavelet shrinkage.

3. **Medical Imaging**

Give short answers to each of the following:

(a) How are images acquired using ultrasound?

(b) Very roughly, what do T_1 and T_2 refer to in MRI image acquisition?

(c) What is the Radon Transform, and why is it significant to medical imaging?

(d) What are some tradeoffs between X-ray CT (computed tomography) and MRI ...

  i. For the patient,

  ii. In terms of the acquired images.

(e) What is *speckle* noise and in what sorts of contexts does it occur?

(f) What are the factors which limit the spatial resolution of an MRI instrument?

(g) Specifically, what makes 3D medical imaging more challenging than 2D?

4. **Image Restoration**

There are a number of image distortions or degradations from which we may wish to recover or restore the original image. In particular, four particularly common degradation / restoration problems are

Degradation		**Recovery**
Adding Noise	$\Rightarrow$	Denoising
Removing Image Pieces	$\Rightarrow$	Inpainting
Blurring	$\Rightarrow$	Deblurring
Downsampling	$\Rightarrow$	Upsampling / Super-resolution

For *each* of these four problems:

a. Describe a context, real-life or otherwise, in which this degradation appears.

b. Offer a mathematical formulation of the degradation.

c. Briefly describe one or two methods / strategies which are used to solve the recovery.

5. **Application — Cell Studies**

There is a great deal of research interest in detecting and tracking individual cells over time in microscope images. Significant applications include embryonic development, stem-cell research, the study and cataloguing of how proteins interact with cells, and the study of exposed cells such as the cells of the cornea or the retina.

Suppose we wish to study stem cells. These cells live, move, periodically divide, and at some point suddenly change into a particular tissue type (skin cell, bone cell, muscle cell etc).

One research interest is to understand what causes a stem cell to become a particular tissue; why did it become skin as opposed to bone? To understand this we need to track the cell over time, to see how much or little it moved, how close to or far from other cells it was etc.

The cells are round, and when viewed through a confocal microscope have a bright ring (the cell wall) and a bright middle (the nucleus) and are otherwise dark.

Your Task:

Assume that there is a microscope system returning large images I_t at time t. Cells have a diameter of 15 to 25 pixels. Images are captured on a time interval of one minute, and over this one minute cells do not typically move further than a cell diameter.

To limit cell death, the scene is only weakly illuminated, so the signal-to-noise ratio is poor (low contrast).

Cells may be on their own, or may be clumped in groups.

You need to design a system that tracks cells over time:

- Return a count of the number of cells in each image
- Return the trajectory for each cell, giving the x, y location of the cell in all past frames
- Identify probable times and locations of cell division.

Be sure to describe the system carefully. You are providing a high level design: you do *not* need to produce a computer program, although you could choose to write some pseudocode.

6. **Application — Skin Cancer**

Melanoma is a form of skin cancer which affects many people in Canada. You wish to develop an image processing algorithm to permit the assessment of skin lesions and the possible detection / classification of melanoma from visual images of the skin.

A skin lesion is a small area of skin (1 to 10 mm in width), slightly raised, and pigmented (coloured).

Lesion irregularity is a strong indicator of melanoma. So we are interested in lesions with irregular (non-round) shapes, and lesions with irregular (non-constant) colouring.

Your Task:

There are basically two steps:

(a) We need to find / localize / segment the lesion

(b) We need to classify the lesion

Given a colour RGB image I at a pixel resolution of 0.1 mm, describe your strategy for the above steps, either in pseudo-code form or as a block diagram. State any assumptions you make.