COL783 Assignment 4

Due date: 11 November 2024

In this assignment we will work with morphological image processing, edge detection, and segmentation. As usual, you are advised to use single-component (intensity) images for all problems. You should use images of at least size $\max(M, N) \geq 500$ for all examples. Larger images ($\max(M, N) \geq 1000$) will make it easier to get better results.

Part 1

1. Take a scan of a printed document with lots of lowercase text, such as this example from the textbook (you can use this example itself, for a penalty of 0.5 marks). Crop the image so it contains a similar amount of text as the above example, i.e. about 50-100 words, and make sure the original resolution was sufficiently high that the resulting image is large enough. Threshold and negate it to get a binary image A where the text pixels are 1 and the background is 0.

   a. Implement binary erosion and dilation using a user-specified structuring element. Demonstrate dilation and closing on A using a moderately sized disk-shaped structuring element. In this part you don't need to show erosion or opening, which may remove all the letters.

   b. Manually crop a lowercase letter "c" from the image to use as a structuring element B. (You can use an interactive image editing tool for this.) Perform opening with B and show the result. Discuss in your report why not all the c's in the text were found. In this and the following subparts of this question, show the results by creating an RGB image where the red component is A and the green and blue components are the detected letters. Thus, all detected letters will be white and the undetected letters will be red.

   c. Perform one or more morphological operations on B so that the new SE, B_1, is able to find all the c's. It will probably also find other letters that are a superset of B_1, such as some lowercase e's. In your report, show the result and explain what you did to obtain B_1.

   d. To get only the c's, you will have to use a hit-and-miss transform using B_1 and another structuring element B_2. Construct B_2 via some morphological operations on B such that you get all the c's in A, and no other letters. Again, explain how you obtained B_2 and show the results.

2. A fundus image is a photograph of the rear surface of the eye, such as these examples on Wikimedia Commons. Choose one of the images on the linked page to use as the input f — don't pick one of the illustrations, pick a real photograph that is sharp and well in focus. The task is to extract the blood vessels in the image and estimate their thickness distribution.

    a. Implement grayscale erosion and dilation using an user-specified *flat* structuring element, and show the results of all four basic operations (erosion, dilation, opening, closing) on f using a moderately sized disk-shaped structuring element.

    b. Use a bottom-hat transform with a disk-shaped SE to extract the blood vessels in f. Try to choose the radius of the disk so that all the vessels are retained, and other intensity variations are removed. You may need to stretch the contrast of the resulting image to see it better.

    c. Since the vessels are reflective, some have a bright highlight in the middle (appearing as a dark gap in the bottom-hat transform). This will affect the thickness estimation and so should be removed. Perform one or more grayscale morphological operations to remove the gap while affecting the rest of the vessels as little as possible. Explain what you did in your report.

    d. Using morphological operations similar to the granulometry technique discussed in class and in the textbook, produce a graph from which one can estimate the typical thickness(es) of the vessels in the image. In your report, discuss your procedure and explain what you conclude about the thickness distribution.

PART 2

3. Choose one of these images containing various round objects: coins1.png, coins2.png, chips.png, citrus.jpg. The goal is to find as many of these objects as possible.

    a. Explain how to perform Marr-Hildreth edge detection using various operations that are already implemented or built-in, such as Gaussian filtering, Laplacian, thresholding, and morphological erosion/dilation. (You can choose to detect all edges, or only the strong ones). Test it on the clown image shown in class, and on your chosen image from the above four.

    b. Applying the Laplacian to a Gaussian-filtered image incurs significant numerical error from the discretization of the Gaussian kernel. Instead implement the difference-of-Gaussian (DoG) approach explained in the textbook. Explain how to obtain the s.d.'s σ_1, σ_2 for a given ratio 1:1.6 and a desired LoG s.d. σ. Compare the computed Marr-Hildreth edges from LoG and DoG on the same image as before.

    c. Use a built-in Canny edge detector (e.g. `skimage.feature.canny` or `cv.Canny`) on the original image. Tune the parameters of both Marr-Hildreth and

Canny to detect all the desired edges and as few of the irrelevant edges as possible. Show the results of both algorithms and report the parameters used.

d. Finally, we can try detecting circles. Implement a circular Hough transform with parameter space (c_x, c_y, r) and use it to find the circles with the most edge pixels lying on them. For speed, you may use a spacing s greater than 1; for example, if $s = 10$, you would consider circles with center coordinates $c_x, c_y = 0, 10, 20, \ldots$ and treat the radii as bins $r \in [0, 10], [10, 20], \ldots$. Find the top k circles from the circular Hough transform and draw them, either on top of the original image or in a separate plot.

4. Now we will try region-based segmentation via thresholding and clustering. Test images are provided in each subpart.

   a. Implement binary thresholding in two ways: using Otsu's method, and using k-means clustering on the intensity values. For efficiency, your algorithm should work only on the histogram of the image. Show the results on one of these images shown in class: polymersomes.tif, yeast.tif, blob.tif. Report the thresholds, the cluster means, and the between-class and inter-class variances for both methods. Discuss which method gives a better segmentation and why.

   b. Extend your k-means clustering algorithm to work on colour images, now using on the pixel values directly as 3-dimensional data points instead of building a histogram. Use one of the images from the Berkeley Segmentation Dataset, e.g. 118035, 189011, 210088, 302003. Choose some value of k appropriate for your chosen image, and perform k-means clustering several times with randomly chosen initializations. Show the results along with the between-class variances, and comment on the variability in the output.

   c. **Optional (for 10% extra marks):** Extend your k-means implementation to compute superpixels using the SLIC formulation. Use a value of s between 10 and 20 pixels. Visualize the result on the same image from part (b) in two ways: one image in which each pixel's intensity is replaced by the cluster mean, and one image in which only the edges of the superpixels are highlighted.

Submission

Submit a zip file that contains (i) all your code for the assignment, and (ii) a PDF report that includes your results for each of the assignment problems. The report must include the name of all teammates who worked on the project. Each output image in the report must be accompanied with a brief description of the procedure used to create it, and the values of any relevant parameters.

All images should ideally be saved in PNG format, which is lossless and so does not cause any information loss (other than quantization if the intensities are not already in 8-bit format). JPEG is permitted if your submission PDF is becoming too big for the upload limit.

Your assignment should be submitted on Moodle before midnight on the due date. Only one person in a group needs to submit. Late days are counted with a quantization of 0.5 days: if you cannot finish the assignment by midnight, get some sleep and submit by noon the following day.

Separately, each of you will individually submit a short response in a separate form regarding how much you and your partner contributed to the work in this assignment.