Exam 020823 – Computerized Image Analysis

Time: 9.00-14.00
Place: PS, sal 2
Tools: calculator, beta Mathematics handbook
Grades:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - U</td>
<td>18 - 3</td>
</tr>
<tr>
<td>0 - U</td>
<td>18 - G</td>
</tr>
<tr>
<td>25 - 4</td>
<td>27 - 40 VG</td>
</tr>
<tr>
<td>32 - 40</td>
<td>5</td>
</tr>
</tbody>
</table>

OBS! Please hand in your solutions in numerical order with a new sheet of paper for each new problem. Please use drawings and figures to illustrate your answers when suitable. You might write either in Swedish or in English.

Results will be posted outside the TDB office in house 2, and outside “civilingenjörskansli” at Polacksbacken. The result will also be posted on the course web page (http://www.cb.uu.se/~xavier/Teaching/BildanalysVT02/BAvt02.html) if you give us your permission to do so by putting an X in the box for this on the exam cover. The results will not be posted if you fail the exam.

Good luck!

1 Segmentation (5p)

a) Explain, employing appropriate illustrations of techniques and applications, the three image segmentation categories:

- single pixel classification,
- boundary based methods,
- region growing methods.

b) Use a boundary based technique to segment the image shown below. The result should be a number of regions, separated by one-pixel thick boundaries.

```
1 2 3 1 3 2 3 1 2 3
2 3 1 3 2 3 1 2 3 1
3 1 3 2 3 8 2 3 1 2
1 2 3 7 8 9 9 8 7 1
2 3 1 8 9 9 8 7 7 2
3 1 2 9 9 8 7 7 8 3
3 1 2 9 9 8 7 7 8 3
1 2 3 1 3 2 3 1 2 3
2 3 1 3 2 3 1 2 3 1
3 1 3 2 3 1 2 3 1 2
```

2 Image compression (4p)

a) Explain, giving examples of each, LOSSLESS and LOSSY data compression.

Xavier
b) Explain applications for which each is (i) definitely appropriate, (ii) definitely inappropriate. (1p)
c) Explain a 'fidelity criterion' for lossy data compression. (1p)

3 Image enhancement (7p)

a) In the context of image enhancement describe the principles underlying: point operations, and neighbourhood operations. Your answer should include representative examples of each, together with illustrations of their operation, and descriptions of applications for which one type is more suitable than the other. (3p)

b) The following equation defines a statistics based contrast stretching transformation,

\[ z' = (z - m) \frac{s'}{s} + m' \]

where \( z' \), and \( z \) are, respectively, the output and input values, \( s' \), \( s \) are the output and input standard deviations, \( m' \), \( m \) are the output and means. Discuss this transformation both in the context of general image enhancement and of part (a); e.g., compare it to other transformations, and to other methods used to obtain the transformation parameters, discuss in what circumstances it might be used, give illustrative examples, etc. (2p)

c) Apply the provided equation to the image shown below, using the values \( m' = 128, s' = 40 \). Comment on the significance of the values \( m' = 128 \), and \( s' = 40 \). (2p)

4 Distance transform (3p)

a) Compute the city-block distance transform of the object below. (For the city-block distance, the distance between two pixels is equal to the number of steps in a minimal 4-connected path between the two pixels). Use the solution sheet provided. (1p)
b) The concept of using watersheds is based on visualizing a 2D image in three dimensions, two for spatial coordinates and one for grey-levels. Explain how this can be used for segmentation and identification/separation of objects. Illustrate using the distance transform computed in (a). (2p)

5 Descriptors (5p)

a) Texture can to some extent be analyzed using directly the grey-level histogram of the image. How? What limitations are there? (1p)

b) Another way is to describe texture by means of a grey-level co-occurrence matrix for a suitable position operator. Describe how such a matrix is constructed. What tools can be used to analyze it? Give two examples of position operators and explain what texture they intended to respond to. (2p)

c) Sketch the result after a skeletonization algorithm based on the Euclidean distance has been applied to a circle, a square, a rectangle, and an equilateral triangle. Remember that the object can be recovered from its skeleton by taking the union of the maximal discs corresponding to the points/pixels in the skeleton. (2p)

6 Mathematical morphology (4p)

a) Sketch the result after erosion of $A$ by structuring elements $B_1$, $B_2$, $B_3$, and $B_4$. The black dots denote the origin. (2p)

b) Filling holes in an object or filling an object given its boundary can be performed using morphological operators. Describe how this can be done. Perform region filling (using a suitable structuring element) starting from
the boundary $A$ (grey) and the initial point $X_0$ (dark grey). Motivate your choice of structuring element. Illustrate the region filling algorithm using the solution sheet provided.

(2p)

7 Classification (4p)

Stina

a) For the multispectral image (3 channels) below, we have the following training data:

<table>
<thead>
<tr>
<th>pixel</th>
<th>class</th>
<th>channel 1</th>
<th>channel 2</th>
<th>channel 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\omega_1$</td>
<td>248</td>
<td>244</td>
<td>243</td>
</tr>
<tr>
<td>2</td>
<td>$\omega_1$</td>
<td>247</td>
<td>243</td>
<td>240</td>
</tr>
<tr>
<td>3</td>
<td>$\omega_1$</td>
<td>248</td>
<td>244</td>
<td>243</td>
</tr>
<tr>
<td>4</td>
<td>$\omega_1$</td>
<td>249</td>
<td>245</td>
<td>249</td>
</tr>
<tr>
<td>5</td>
<td>$\omega_2$</td>
<td>174</td>
<td>164</td>
<td>49</td>
</tr>
<tr>
<td>6</td>
<td>$\omega_2$</td>
<td>177</td>
<td>169</td>
<td>36</td>
</tr>
<tr>
<td>7</td>
<td>$\omega_2$</td>
<td>184</td>
<td>170</td>
<td>65</td>
</tr>
<tr>
<td>8</td>
<td>$\omega_2$</td>
<td>195</td>
<td>189</td>
<td>91</td>
</tr>
<tr>
<td>9</td>
<td>$\omega_3$</td>
<td>170</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td>10</td>
<td>$\omega_3$</td>
<td>156</td>
<td>68</td>
<td>46</td>
</tr>
<tr>
<td>11</td>
<td>$\omega_3$</td>
<td>142</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>12</td>
<td>$\omega_3$</td>
<td>118</td>
<td>19</td>
<td>39</td>
</tr>
</tbody>
</table>

The training data is picked from the marked regions. Your task is to classify the pixels in the image into class $\omega_1$ (table), $\omega_2$ (leaf), and $\omega_3$ (berry) using the information in the training data set. You are only allowed to use two channels. Evaluate visually (using 2D feature spaces) which two channels are the most suited. Give the decision functions for $\omega_1$, $\omega_2$, and $\omega_3$ using Minimum Distance Classifier (using the two selected channels).

(3p)
b) Classify the pixels below using the functions in (b). Note that just giving the class for the pixels will not give any score even if correct. (1p)

<table>
<thead>
<tr>
<th>pixel</th>
<th>channel 1</th>
<th>channel 2</th>
<th>channel 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>200</td>
<td>45</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>169</td>
<td>136</td>
<td>55</td>
</tr>
<tr>
<td>15</td>
<td>231</td>
<td>218</td>
<td>201</td>
</tr>
<tr>
<td>16</td>
<td>203</td>
<td>176</td>
<td>131</td>
</tr>
</tbody>
</table>

The pixels are picked from the marked regions.

8 System design (8p)  
Stina, Xavier

You have been hired by a company producing matches, to evaluate the production process and give suggestions on how to make the production more efficient. At the moment a match that does not fulfill the standard is identified manually and thrown away without any further analysis.

You decide to build a simple image analysis system. In the end of the production process, the matches are “travelling” on a belt conveyor over which it is possible to mount an imaging device (imaging the belt conveyor from any (reasonable) angle). Describe the image acquisition step.

An “ideal” match is shown below. The matches that leave the production should not differ much in length or shape from the ideal match. Matches not fulfilling the demands can (roughly) be divided into three classes: too short, too long, and missing head. The matches that are too long or without head do not need to be thrown away. For each match you decide which class the match belongs to. Describe how this can be done, given an image where the matches are placed in a way similar to the image below. You should describe all steps, starting from the digital image until the decision has been taken.

For the company it is of interest to know the rate of matches not fulfilling the criteria, and how many of the removed matches can be put into the production process again.
You do not need to think about how to organize the step about actually removing the match as you have a well-working picking machine connected to the image analysis system that takes care of that once the decision has been taken.

Remember to describe what limitations your solution has and what (and why!) simplifications you have done.
Distance transform
Mathematical morphology