Advanced Informatics and Control

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Introduction to Computer Vision in Quality Control

Choose yourself and new technologies

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Wrocław University of Technology
EUROPEAN SOCIAL FUND
Project co-financed from the EU European Social Fund

Introduction to Computer Vision in Quality Control

Lecture 7 – Finding objects III

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Summary of Lecture 6

Methods of finding objects II

Summary of Lecture 7

Industrial Image Processing 7
Labeling objects

Recall that thresholding is the method for selecting objects using gray levels (illumination) as the only information.

Recall from Lecture 6: A binary image obtained as the result of thresholding bears important information for a human being, but it is still not ready for gauging, recog. etc.

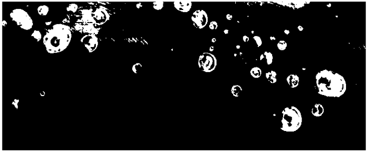
A group (heap) of marked pixels, which are separated from other groups, is called a <u>blob</u>. Blobs are candidates for objects.

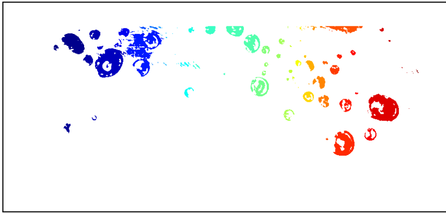
Example of marked pixels.

Technical remark: note the change of convention – most algorithms and available software work on blobs marked as WHITE = 1 (or 255).

Industrial Image Processing 7
Labeling objects 3

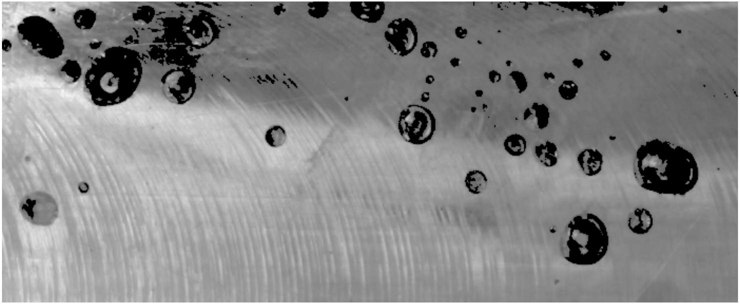
Our aim – to attach different labels to different blobs (hopefully – objects, defects etc.). It is customary to use positive integers as labels and to display them as pseudo-color images, as below:





Industrial Image Processing 7
Labeling objects 5, Some remarks:

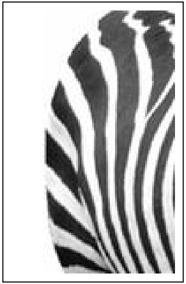
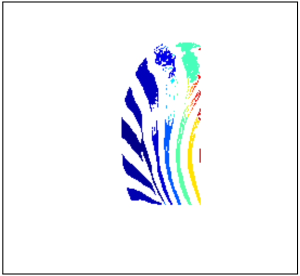
- **It is customary to fill "holes" in blobs before labeling them. It is not always appropriate (e.g., bored holes). In our case also:**



since craters are clearly visible and informative.

Industrial Image Processing 7
Labeling objects 6, Some remarks:

- Blobs are not always objects:

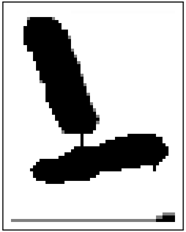
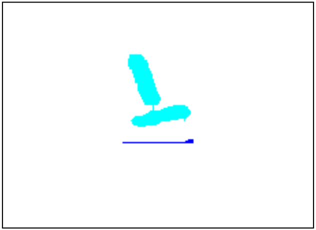



blobs and their labeling by pseudo-colors. Our zebra would not be happy for being treated as separate parts.

Industrial Image Processing 7
Labeling objects 7, Some remarks:

Why two pills are colored as one ?

- **Why it is not so easy, even in a simple case:**

Note a thin line between pills – the thresholding process is not not always enough, sometimes a kind of postprocessing is necessary (cleaning small groups of pixels, e.g., by morphological operations).

Industrial Image Processing 7

Labeling objects 8, Connected components:

What does it mean that a group of marked pixels is connected ?

	M	M	M	M	
	M	M	M	M	
	M	M	M	M	
	M	M	M	M	

	M	M			
	M	M			
			M	M	
			M	M	

Left table – there are no doubts. Right table – it is our choice to consider them as connected or not.

Industrial Image Processing 7
Labeling objects 8, Connected components:

For the central (currently considered) pixel (marked as $\mathcal{M}$) we can distinguish two cases:

	M	M	M		
	M	$\mathcal{M}$	M		
	M	M	M		

		M			
	M	$\mathcal{M}$	M		
		M			

Left – 8-connected components. Right – 4-connected components. Pixels marked by M in the surrounding of $\mathcal{M}$ are treated as belonging to the same clique.

Industrial Image Processing 7
Labeling objects 9, Connected components:

The way of treating neighbors depend on selected connectivity.

		M			
	M	$\mathcal{M}$	M		
		M	A		
				A	
					A

Pixels marked by "A" are not treated as the same clique as those marked by "M" if 4-connected component treating is selected, but they are from the same clique when 8-connected components are in use.

Industrial Image Processing 7
Labeling objects 10, Connected components:

- The above way of defining connected components is the only one used in the literature.
- At the pixel level there are no other choices.
- However, is it the only reasonable way of defining connected components when we have 10 MPix images ? Think about that.

OK, but finally, how to label marked pixels ?

Industrial Image Processing 7
Labeling objects 11, Labeling algorithms:

- There are many labeling methods – this means that:
  - the task is difficult
  - none of them is superior in all the categories.
- They differ in:
  - ease of programming,
  - speed,
  - memory requirements.
- The last two being interchangeable.

Industrial Image Processing 7
Labeling algorithm, Preparations :

- For simplicity we consider 4-connected components only.
- Given $M \times N$ binary image $b_{ij} \in \{0, 1\}$.
- Allocate a memory for labels (either $M \times N$ matrix L_{ij} or a list of labels and addresses).
- Allocate also an auxiliary $2 \times \mathcal{N}$ table C for resolving conflicts of labels, where $\mathcal{N}$ is the maximum number of blobs that are expected to be labeled.

In fact, $\mathcal{N}$ should be somewhat larger so as to store also parts of blobs, which are later glued.

Industrial Image Processing 7
Labeling algorithm, Outline I a:

- **Starting from the upper left corner, scan the image b_{ij} unless the first marked pixel is found and and set the corresponding label in L to "1". Unmarked pixels – $b_{ij} = 0$ are skipped (we set their L_{ij}'s to "0").**
- **In a general position (i, j), $i \geq 1$, $j > 1$, say, pixels above and to the left have labels already attached. Let "n" denotes the largest of them. L_{ij} = "1". Now, the following three cases may appear:**

Industrial Image Processing 7

Labeling algorithm, Outline I b:

- unmarked pixel: $b_{ij} = 0$ – set $L_{ij} =$ "0", $j := j + 1$ (or change the row).
- marked pixel: $b_{ij} = 1$ AND $L_{i(j-1)} =$ "0" AND $L_{(i-1)j} =$ "0", set $L_{ij} =$ "$n + 1$" (set the next label) and $j := j + 1$ (or change the row).
- marked pixel: $b_{ij} = 1$ AND [$L_{i(j-1)} >$ "0" OR $L_{(i-1)j} >$ 0"0"] splits into two cases:

Industrial Image Processing 7
Labeling algorithm, Outline I c:

Case 1 **"previous labels agree", i.e.,**
$L_{i(j-1)} = "m"$ AND $L_{(i-1)j} = "m"$,
where "m" is one of assigned labels "1", "2", . . . , "n".

Case 2 **"not all previous labels agree"**

			j		
		"m"	"m"		
i		"m"	new "m"		

L - matrix – Case 1

			j		
		"0"	"k"		
i		"m"	new "??"		

L - matrix – Case 2

Industrial Image Processing 7
Labeling algorithm, Outline I d:

Case 1 **Set $L_{ij} =$ "m",**

Case 2 **Set $L_{ij} =$ "??" – assign the "smallest" label between conflicting, i.e., "k" or "m" (not "0" if present)**

Set $j := j + 1$ (or change row). Stop if (i, j) at the lower right corner. •

So far, so good ?? Not yet ! Imagine a triangle: $\triangle$. How it will be colored by the above algorithm ?

Industrial Image Processing 7

Labeling algorithm, resolving conflicts:

$2 \times \mathcal{N}$ matrix C is filled simultaneously with L matrix in the above algorithm, according to the following rules:

- The first row of C always contains $1, 2, \ldots, \mathcal{N}$ (in fact, it is used for convenience only). At the beginning, the second row of C contains "0"'s at each position.
- When new blob starts, i.e., when

			j		
		"0"	"0"		
i		"0"	new "n+1"		

Industrial Image Processing 7
Labeling algorithm, resolving conflicts 2:

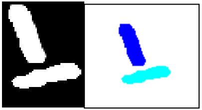
then, in the second row of $(n+1)$-th column of C we set "$n+1$" (in agreement with L).

- If there is a conflict of labels, in the second row of C, we set the largest among conflicting labels ("m" or "k").

Note that C contains information on conflicting labels, which is complementary to that stored in L. This information is sufficient to resolve conflicts once again, by looking up L and C once again and changing labels, when necessary.

Industrial Image Processing 7
Labeling – example

Now we can label and gauge our pills, since we exactly know, which pixel belongs to each blob.



Area	493	396
Centroid	[16.2 21.0]	[29.5 47.5]
Major Axis Length	44.1	47
Eccentricity	0.94	0.97
Orientation	-67.9	12.6
Euler Number	1	1
Perimeter	102.7	100.8

We shall define these notions later.

Industrial Image Processing 7
Finding objects by a template matching

This approach is well suited if we have to find and locate a precisely defined template (pattern) on an image. We need:

- image of template, usually much smaller than the image on which we look for the presence of a pattern,
- a similarity measure between a template and a part of image.
- the matrix R, say, of the same size as the image.

Industrial Image Processing 7
Finding objects by a template matching 2

Outline of the method.

- The template is tried to fit pixel after pixel to the whole image,
- at each of its position the selected similarity measure is calculated and stored in R
- The border problem (as usual) arise. It is solved either by zero padding or by omitting near boundary pixels when the image is scanned by the template.

Industrial Image Processing 7
Finding objects by a template matching 3

The method is:

- time consuming,
- sensitive to the size of searched objects and their rotations,
- but still useful and applicable both to binary and gray level images
- and not too sensitive to illumination changes.

Industrial Image Processing 7
Finding objects by a template matching 4

The empirical correlation coefficients r (or its simplified variants) are the most frequently used as the measure of similarity between the template and the currently considered part of the image. Recall that for two vectors $x = [x_1, x_2, \ldots, x_n]$ and $y = [y_1, y_2, \ldots, y_n]$ of equal lengths, r is defined as follows:

$$r(x, y) = \frac{n^{-1} \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sigma_x \cdot \sigma_y} \qquad (*)$$

where $\bar{x}$ and $\bar{y}$ are the (empirical) means, while σ_x and σ_y are the dispersions.

Industrial Image Processing 7
Finding objects by a template matching 5

When r(x, y) is applied for the template x matching, it is calculated as follows:

x_1	x_2	x_3
	●	
x_7	x_8	x_9

y_1	y_2	y_3						
	●							
y_7	y_8	y_9						

where ● indicates the coordinates of the result r(x, y) in R matrix and the way of alignment of the template x and the current sub-image y.

Industrial Image Processing 7
Finding objects by a template matching 6

When all the matrix R is calculated, then $(i^*, j^*) = \arg\max |r_{ij}|$ is calculated. If $|r_{i^* j^*}|$ is sufficiently close to 1, we claim that the template was found at the point (i^*, j^*).

The following simplifications can be made in order to speed up calculations:

- Coarse-to-fine search – r_{ij} is calculated firstly every 8-th pixel, say, taking into account that the correlation is large even if the template not exactly matches an object. Then, the maximum from calculated $|r_{ij}|$ is found and the search is limited to its neighbors.

Image Processing 7

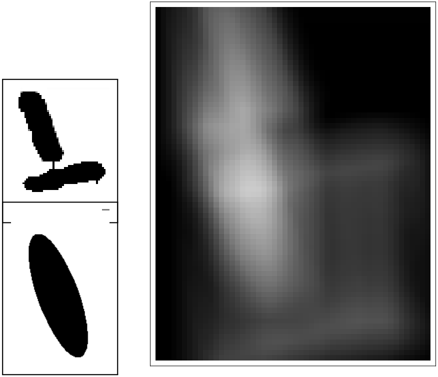
Finding objects by a template matching 7

- Formula (*) can be rewritten as:

$$r(x,\ y) = \frac{n^{-1}\ \sum_{i=1}^{n} x_i\, y_i - \bar{x}\, \bar{y}}{\sigma_x \cdot \sigma_y}$$

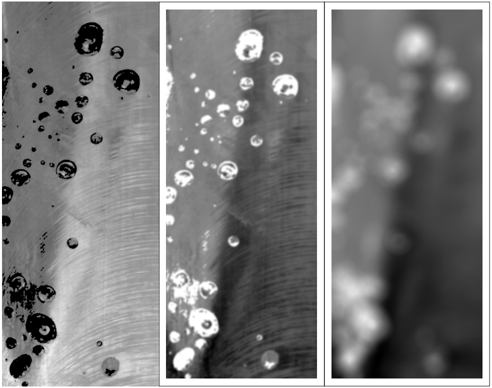
- σ_x and $\bar{x}$ depend on the template only – they are constant. If there are not too many changes in the image intensity, then in the most places (except those near the object), also σ_y and $\bar{y}$ are approximately similar.
- For locating the template only the term $n^{-1}\ \sum_{i=1}^{n} x_i\, y_i$ is used.

Image Processing 7
Finding objects by a template matching 8



Example: pills, the template and R matrix – white corresponds to $R_{ij} \approx 1$.

Image Processing 7
Finding objects by a template matching 10



Example – the technique applies also to gray-level images (left). Here the template was the disk of radius 2 pixels (middle) and 20 pixels (right).

Further reading

- Otsu, N., "A Threshold Selection Method from Gray-Level Histograms," IEEE Transactions on Systems, Man, and Cybernetics, Vol. 9, No. 1, 1979, pp. 62-66.
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