Advanced Informatics and Control

Ewaryst Rafajłowicz

Introduction to Computer Vision in Quality Control

Choose yourself and new technologies

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Wrocław University of Technology

EUROPEAN SOCIAL FUND

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Introduction to Computer Vision in Quality Control

Lecture 6 – Finding objects II

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Summary of Lecture 5

Methods of finding objects I

- Segmentation by thresholding
- Automatic threshold choice
- Selecting threshold using Bayesian classifier
- Other statistical methods
- Segmentation by thresholding – Discussion

Summary of Lecture 6

Summary of Lecture 5

Simple algorithms

Selecting threshold without histogram

Introductory remarks on "adaptive" thresholding

A remark on segmentation using colors

Remarks on blob analysis

Further reading

Industrial Image Processing 6
Thresholding – cont.

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

Simple thresholding:

- Select threshold $T \in (0, 255)$ – by the histogram analysis or "automatically".
- For each pixel set:

$$y_{ij} = \begin{cases} 0 \text{ (black)} & \text{if} \quad f_{ij} \leq T, \\ 1 \text{ (white)} & \text{if} \quad f_{ij} > T \end{cases}$$

Note that objects are marked as black.

Industrial Image Processing 6
Simple algorithms 1

We concentrate mainly on the methods, which are used in machine-vision setups for industrial quality control, and more concerned with reproducibility than with absolute accuracy.

- "The rule of thumb:" If we have a repeatable production process and artificial, well tuned illumination, which guarantees existence of only two peaks in the histogram, then one can select T in the half way between them.
- Not applicable when the "hills" are of essentially different sizes.

Industrial Image Processing 6
Simple algorithms 2

The following method works well, in applications such as locating objects (black, say), where the position of the objects may vary but their total area will remain constant.

- Calculate the percentage of the image area usu. occupied by objects – denote it by D.
- Calculate the histogram $\hat{p}_l$, $l = 0, \ldots, 255$.
- Find the smallest k for, which

$$\sum_{l=1}^{k} \hat{p}_l > D$$

and take it as T.

Industrial Image Processing 6
Simple algorithms 3

As in Lect. 5, let n_l be the number of pixel having gray level $l \in \{0, 1, \ldots, 255\}$. Clearly, $\sum_{l=1}^{255} n_l = N \cdot M$ – the total number of pixels.

Define:

- $\hat{p}_l = n_l/(N \cdot M)$,
- $\hat{\pi}_0(t) = \sum_{l=1}^{t} \hat{p}_l, \quad \hat{\pi}_1(t) = 1 - \hat{\pi}_0(t)$,
- $\hat{\mu}_0(t) = \hat{\pi}_0^{-1}(t) \sum_{l=0}^{t} l\, \hat{p}_l$
- $\hat{\mu}_1(t) = \hat{\pi}_1^{-1}(t) \sum_{l=t+1}^{255} l\, \hat{p}_l$

Industrial Image Processing 6
Simple algorithms 3

- $\sigma_0^2(t) = \hat{\pi}_0^{-1}(t)\ \sum_{l=0}^{t}(l - \hat{\mu}_0(t))^2\ \hat{p}_l$
- $\hat{\sigma}_1^2(t) = \hat{\pi}_1^{-1}(t)\ \sum_{l=t+1}^{255}(l - \hat{\mu}_1(t)^2\ \hat{p}_l$

Define also the well known statistic for testing the hypothesis on the difference of two means in two normal populations:

$$\text{Student}(t) = \frac{|\hat{\mu}_0(t) - \hat{\mu}_1(t)|}{\sqrt{\frac{\sigma_0^2(t)}{N_0(t)} + \frac{\sigma_1^2(t)}{N_1(t)}}},$$

where $N_0(t) = \sum_{l=0}^{t} n_l$, $N_1(t) = \sum_{l=t+1}^{255} n_l$.

Industrial Image Processing 6
Simple algorithms 4

Trussell's method (1979):

Select $t \in \{0, 1, \ldots, 255\}$, for which these two populations differs as much as possible, i.e.,

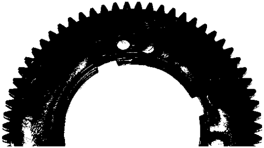
$$T = \arg \max_{t} \mathrm{Student}(t)$$

is attained.

From The Image Processing Handbook "The Trussell algorithm is probably the most widely used automatic method because it usually produces a fairly good result and is easy to implement."

Industrial Image Processing 6

Simple algorithms 5



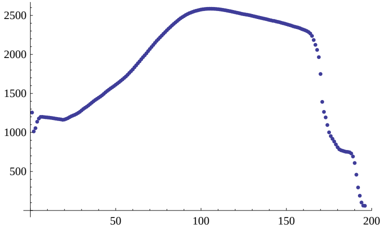


Figure: **The plot of Student(t) statistic has max. at T = 110 – right panel. The result of using T = 110 – left panel.**

The result of thresholding is not satisfactory – the Bayes threshold gave much better result.

Industrial Image Processing 6

Simple algorithms 6

The Trussell method is easy to implement, but rather time consuming. In many cases its simplified version:

$$T = \arg \max_t |\mu_0(t) - \mu_1(t)|$$

provides similar thresholds at much lower computational costs. The rationale behind this simplification is in that the function:

$$\sqrt{\frac{\sigma_0^2(t)}{N_0(t)} + \frac{\sigma_1^2(t)}{N_1(t)}}$$

is frequently flat, with the exception of near boundary regions.

Industrial Image Processing 6
Avoiding histogram in selecting T

Three very simple methods:

- $T = \hat{\mu}$ – the empirical mean of gray levels,
- T= the empirical median of gray levels,
- $T = k_1 \hat{\mu} + k_2 \hat{\sigma}$, $\hat{\sigma}$ – the empirical dispersion, $k_1 > 0$, $k_2 > 0$ – constants to be selected (typical choice: $k_1 = 1$, $k_2 = 0.5 \ldots 2$)

not always gives good results.

Industrial Image Processing 6
Avoiding histogram in selecting T – example

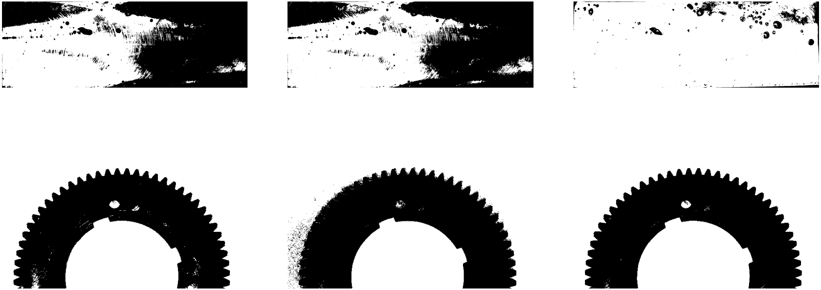


Figure:
T=mean, **T**=median, $\mathbf{T} = \hat{\mu} + 0.5 \cdot \hat{\sigma}$

The result is not always acceptable. k_1, k_2 – selected by the trial and error method.

Industrial Image Processing 6

Avoiding histogram in selecting T – Kittler-Illingworth method 1

also called "SIS – simple image statistic".

For each pixel (except – boundary layer) set:

$$D_{ij} = \max[|f_{(i-1)j} - f_{(i+1)j}|, f_{i(j-1)} - f_{i(j+1)}|]$$

$$\acute{T} = \frac{\sum_{i=2}^{M-1} \sum_{j=2}^{N-1} f_{ij} \cdot D_{ij}}{\sum_{i=2}^{M-1} \sum_{j=2}^{N-1} D_{ij}}$$

Industrial Image Processing 6

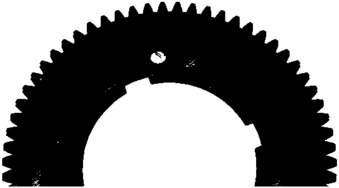
Avoiding histogram in selecting T – Kittler-Illingworth method 2

Provided that at least one $\neq$ (otherwise, the image contains only one gray level).

Justification: Note that D_{ij} is large only when the gradient of gray levels is large near (i, j), in "flat" areas $D_{ij} \approx 0$. Consider an ideal image, which consists only on the background (gray level ="B") and an object (gray level ="O"). It can be shown that then

$$\acute{T} = \frac{B + O}{2}.$$

Industrial Image Processing 6
Avoiding histogram in selecting T – Kittler-Illingworth method – examples



Quite reasonable results in the two quite different cases.

The calculation of the histogram is avoided, but the computational bargain is still large.

Industrial Image Processing 6
Sources of troubles with global thresholding

Global thresholding fails if:

- there is low contrast between the object and the background,
- image is noisy,
- background intensity varies significantly across the image.

Industrial Image Processing 6
Image preprocessing before thresholding

Background correction can be accomplished using one (or both) general approaches:

- by image transformations, which lead to the histogram equalization (later),
- by background correction techniques.

If we can take the image of the background itself b_{ij}, say, then either:

- use it directly by subtracting from the next images, or
- fit (by LSQ's) a simple model $a \cdot i + b \cdot j + c$ to b_{ij}'s and use it for corrections.

Industrial Image Processing 6
Image preprocessing before thresholding

Corrections of the background by division are also used.

Preprocessing by filtering

- reduces noise,
- modes of the histogram higher and better separated,
- but only when edge-preserving filters – like the median filter – are used.

Industrial Image Processing 6
"Adaptive" thresholding

We continue our story on selecting threshold T. Names "adaptive" or "dynamic" thresholding usually are neither adaptive nor dynamic – these names are frequently used for variants of local thresholding, which allow different T for sub-images or even for each pixel. When the former version is used, then information for selecting local thresholds is gained from overlapping neighborhoods. We skip this variant as too time consuming – applicable for medical images.

Industrial Image Processing 6
"Adaptive" thresholding 2

The prescription is simple:

- divide image for sub-images,
- for each sub-image apply one of the above simple methods of selecting the threshold,
- Store thresholds and apply them to, corresponding, sub-images of newly coming images.

Do not use too small sub-images (smaller than 16x16 or 32x32 pixels, say). Otherwise, statistical data are not representative.

Industrial Image Processing 6
Multilevel thresholding

As above, we admit more than one threshold, but regions to which they are applied are not necessarily rectangles – regions are defined in a data dependent way (Tomita et al.)

- Select the threshold using one of the above described methods and apply it to the whole image. Store the coordinates of "black" and "white" regions.
- Form the histograms of gray levels of these parts.
- If the histogram of one of these parts is bi-modal, calculate new threshold and split it as above.
- Continue splitting of all the sub-regions unless all histograms of their gray levels are unimodal.

Industrial Image Processing 6

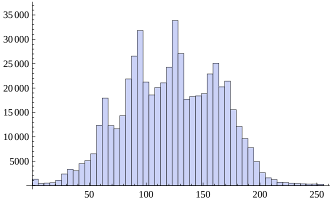
Two-sided thresholding

Up to now, only one threshold T was considered. Sometimes it is known that gray level of the object are contained between T_1 and $T_2 > T_1$ gray levels. In this case: For each pixel set:

$$y_{ij} = \begin{cases} 0 \text{ (black)} & \text{if } T_1 \le f_{ij} \le T_2, \\ 1 \text{ (white)} & \text{otherwise} \end{cases}$$

If the histogram has three modes and the objects have gray levels near the middle mode, then one can select T_1 in the half way between the left and the middle mode and analogously T_2.

Industrial Image Processing 6
Two-sided thresholding – rust penetration



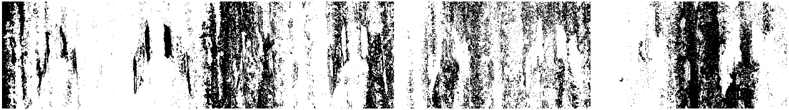


Figure: [0-75], [75-120], [120-150], [150-255]

We can select areas with different levels of the rust penetration.

Industrial Image Processing 6

Thresholding – a remark on segmentation using colors

- Why caps on bottles with milk, yoghurt etc are usually red, green or blue ?
- Segmentation of color images can be very fast, if a color of an object is precisely defined in Red, Green, Blue 3D space.
- It allows to check caps of 200-300 bottles per minute.
- For mixed colors it is better to use HSV (HSI) (Hue, Saturation, Value (Intensity)) space.

Industrial Image Processing 6
Thresholding – segmentation using colors - example

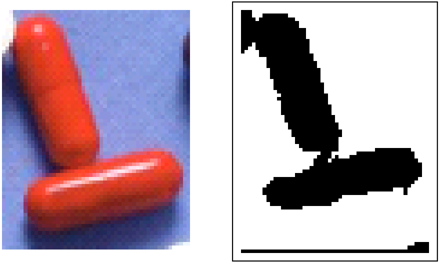


Figure: We can quickly detect red pills, shades are automatically neglected.

Three histograms (for each color channel) can be used for selecting thresholds.

Industrial Image Processing 6
What to do with segmented image ?

A binary image obtained as the result of thresholding bears important information for us, but not for a computer. Why ? It contains marked black pixels and nothing more.

Without further analysis we can only count black pixels (in some cases it is sufficient – says about total area of defects).

Industrial Image Processing 6
Remarks on blob analysis

A group (heap) of marked (black) pixels, which are separated from other groups by white pixels, is called a blob.

Blobs are candidates for objects. Some of them are not objects, which are interesting, some are "ghosts" – they appear as the result of image processing.

So, what can we do with segmented image ?

- Count blobs.
- Fill holes in blobs (caused by not detected parts of an object).

Industrial Image Processing 6
Remarks on blob analysis 2

More advanced (and time consuming) operation on blobs:

- Quickly locate blobs and estimate roughly their dimensions (lateral histogram)
- Coloring blobs
- Gauge blobs (e.g., in order to check whether a product confirm requirements)
- Recognize blobs as objects.

Industrial Image Processing 6
Remarks on blob analysis 3

Coloring blobs serves not only for nice displaying them, but mainly for indicating precisely each pixel belonging to a given blob and to label all of them by the same label. Finally, a data structure, which is convenient for further processing is formed.

Recognizing blobs as objects (defects) is a multistage process. Firstly, we have to select features for a recognizer, then to learn the recognizer to classify objects. Finally, we can use this recognizer on-line.

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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- Pratt, W.K., *Digital image processing*, New York, Wiley, 1991.