Thresholding Method based on the Hmax and Hmin Morphological Operators

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Abstract. This paper presents a new method for thresholding gray level images based on intrinsic properties of the h-extrema Hmax and Hmin morphological operators. Hmax is used to segment the dark objects and Hmin to segment bright objects. Gray levels have a more extended influence over neighbor pixels because all intermediate peaks (troughs) in the original image f are eliminated in a natural way by the process of reconstruction by dilation (erosion) of f from the f − h (f + h) image. It produces a kind of plateau around all pixels that maintain the category of extrema. In practice, our thresholding method includes the pixels located throughout the natural ramp-shaped edge commonly present between adjacent regions having any two different gray levels.

Keywords: . Thresholding, . Hmax . morphological . operator, . Hmin morphological operator, image segmentation.

1 Introduction

Thresholding is a simple and direct method to obtain a binary image from a gray level image. Binary images make easier the description of objects resulting from the thresholding process. In a binary image objects appear black in a white background or vice versa. Thresholding is the simplest procedure for segmenting images. From the programming point of view, it is computationally inexpensive and fast [1] [2].

In principle, any gray level value used as a threshold produces a binary image from a gray level image. However, not every threshold when applied to the gray level image produces a useful binary image. From a gray level image, which can be considered the best thresholding method for obtaining a useful binary image? How can we obtain the best value for the threshold? The answers to these questions are not trivial in any way, because in general the answer depends on the complexity (contents) and on the particular characteristics (contrast, type and rate of the noise, homogeneity of the illumination, and many others) of the original gray level image, and also on the objects we would like stand out in the binary image. As a conclusion, the selection of the appropriate threshold depends on the object(s) we would like

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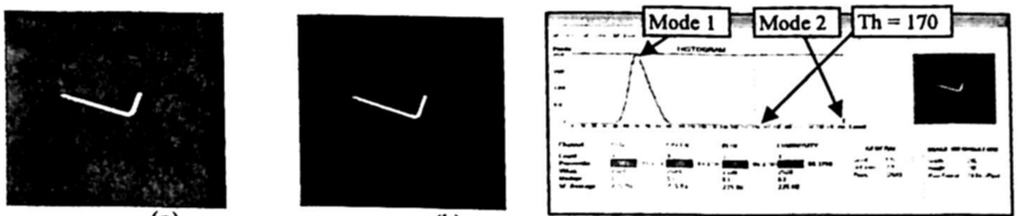
to isolate from the gray level image. Nevertheless, sometimes it is impossible isolate successfully all desired object from a gray level image using the thresholding. Generally, the global statistical characteristic between *gray levels* versus *probability of occurrence* of the image, known as the histogram, is used for selecting the threshold value. There is not a general method for selecting the optimal threshold value in order to get always the best or most useful binary image. In general, the determination of the thresholding value in a non-supervised manner could be done automatically when for a given application we can assure that all images will have similar histograms. For the sake of clarity in this paper the threshold is selected in a supervised way.

Every digital image when digitized acquires random pixel values in a very broad range of levels due to the intrinsic noise produced by a deficient illumination or by non-uniform input device parameters. All gray level images used in this paper to explain the method have not been preprocessed in any way; in other words, they are shown just as they were acquired. This means that images probably have a certain amount of additive noise with a Gaussian, uniform, or random distribution. On the other hand, the jump from regions with bright pixels to others with dark pixels or vice versa is never drastic. In the zone between the bright and dark regions in an image they are found always pixels with gray levels forming a ramp-shaped edge. Due to these two problems mentioned above, the selection of the most suitable threshold to get a useful binary image from a gray level one could be a very difficult and cumbersome task.

In our study we consider two main types of binary images of interest for application researchers and developers: the first type show independent objects clearly distinguished in a contrasting background (Section 2); this is the case in images with a bimodal histogram (Fig. 1) and the process executes a complete segmentation. The second one occurs when a given number of the darkest (or brightest) pixels (in general many pixels) must be clearly distinguished from the remainder in the image (Section 3); this is the case in images with a multimodal histogram (Fig. 2) and the process executes a partial segmentation [2]. These two types of binary images are obtained preferably using only one threshold applied to the original image. From the first type, it is possible later to count the objects after labeling and to calculate for each one the area, perimeter, and other geometrical characteristics in order to classify them according to their size, orientation, etc. In the second type of binary image, the interest could be simply the separation of the darkest (or the brightest) pixels (objects) in order to segment them from the remainder to guide a robot throughout a contrasted line in the floor, for detecting holes in a road, or for locating the position of luminous sources illuminating the scene, reflexes, shadows, among others aims.

Figure 2 shows the image of a house and three binary images obtained from the original in three different arbitrarily manually selected thresholds, Th, in gray levels 141, 169 and 226, respectively (indicated with the arrows), where appear the minima in the histogram in Fig. 3.



(a) (b) (c)

Fig. 1. (a) Gray level image; (b) Binary image; (c) Bimodal histogram

According to the histogram, all values are consecutive relative minima with 16, 7 and 6 pixels, respectively. First two cases clearly segment the darkest zones of the original image, and the third one, segments exclusively the brightest parts of the house. However, how can we assure that these manually selected thresholds are the most adequate? Which from the three thresholds is better to segment the darkest (or brightest) part of the house (or of the whole image)? Which threshold segments the house with a maximum number of dark or bright pixels? How can we select the adequate threshold to segment only the darkest zones of the house (shadows)? Or only the brightest parts of the house? It is practically impossible to find a categorical correct answer to these questions. For the sake of comparing results, from the total 65536 pixels (px), the number of dark and white pixels in three images is shown in Table 1.

Fig. 2. (a) House. Three resulting binary images of the house from three arbitrarily selected threshold levels, Th, in: (b) 141; (c) 169; (d) 226, shown by the arrows in the histogram in Fig. 3

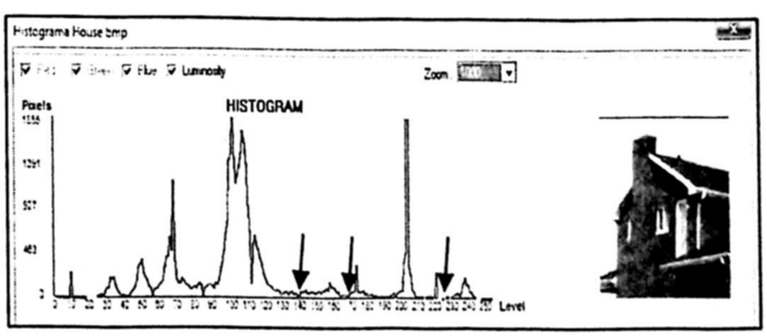


Fig. 3. The histogram of the House

Table 1. Number of white and black pixels in binary images shown in Fig. 2 with the three threshold levels selected arbitrarily

Image	Threshold (Th)	White px	Dark px
b	141	26792	38744
c	169	24498	41038
d	226	1504	64032

2 The Problem

The main purpose of this paper is to explain a relatively simple method to determine the most suitable global threshold that transform a gray level image in a binary one. In this paper a morphological method is proposed to get, in a simple and straightforward way, a more exact global threshold value in gray level images having either a bimodal or a multimodal histogram. The procedure is based on the use of the h-extrema morphological operators, hmax to isolate the dark objects and hmin to isolate the bright objects.

3 Brief State-of-the-Art

Thresholding in image processing is not new. Here, we discuss thresholding methods (pixels-based) requiring only one threshold level and based on the histogram to give as result a binary image. In general, the pixels of the output $g(i, j)$ obtained from the thresholding process fulfils the following conditions [2]:

$$g(i,j)=1 \quad for \quad f(i,j)>T$$
$$g(i,j)=0 \quad for \quad f(i,j)\leq T$$

Where $f(i, j)$ is the original gray level image, $g(i, j)$ is the output binary image and T is the threshold level selected. Brightest pixels are related either to the objects and darkest pixels is related to the background, or vice versa. Many times the threshold is selected by trial and error but it is not obtained the best solution. Frequently, there are many thresholds that produce useful binary images.

There are many classical methods to obtain a binary image using only one threshold level T. Amongst them the following methods are commonly used.

In the variable or adaptive thresholding the image f is divided into subimages f_c [2]. A different threshold is determined independently in each subimage. If the threshold cannot be determined in some subimage, it can be interpolated from thresholds determined in neighboring subimages. Each subimage is then processed with respect to its local threshold.

$$T=T(f,f_c)$$

Optimal thresholding is based on the approximation in the histogram of an image using a weighted sum of two or more probability densities with normal distribution. The threshold is set as the closest gray level corresponding to the minimum probability between the maxima of two or more normal distributions, which results in minimum error segmentation [2], [7].

There are some other methods based on the entropy [3], [4], [5], [8]; on fuzzy sets [6]; on minimum error [7]. There has been also revised the survey [4].

The Otsu method [11] is a commonly used thresholding method. It is a nonparametric and unsupervised method of automatic threshold selection. An optimal threshold is selected by the discriminant criterion of maximizing the separability of the resultant classes in gray levels. The procedure utilizes the zeroth- and the first-order cumulative moments of the gray level histogram. However, the method has failed when the difference between the levels of the objects and the background is small.

Many relatively recent morphological solutions appear in the literature to select the best threshold in gray level images to turn it out a binary one [13]-[19]. However, any of them uses the hmax and hmin operators to carry out thresholding.

4 The H-extrema

The regional extrema of a raw image mark relevant as well as irrelevant image features. H-extrema transformations provide us with a tool to filter the image extrema using a contrast criterion. More precisely, the h-maxima transformation suppresses all maxima whose depth is lower or equal to a given threshold level h. This is achieved by performing the reconstruction by dilation of f, R_f^δ, from $f - h$ [12]:

$$h\max = HMAX_h(f) = R_f^\delta(f - h) \quad (5)$$

The h-maxima transformation is illustrated in Fig. 4 on a 1-D signal.

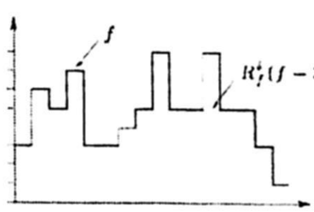


Fig. 4. H-maxima transformation of a 1-D signal using a contrast value of 3 intensity levels

The h-minima transformation is defined by analogy as:

$$h\min = HMIN_h(f) = R_f^\varepsilon(f + h) \quad (6)$$

Where R_f^ε is the reconstruction by erosion of *f*.

The size of the structuring element used in these operations, is the elemental one, that is, the smaller commonly used by the processes of reconstruction. In our case, we used a 3 x 3 square flat structure element.

5 The Method

The method for thresholding gray level images could be supervised or non-supervised. In this paper we explain the supervised version of the method. Also, the particular method varies if the user is interested in selecting the darkest or the brightest objects (or zones). The most straightforward and easy way depends on the number of gray levels of dark (or bright) pixels we can appreciate in the image. The exact division between which gray levels can be considered as dark or bright in a particular image is not so easy, although obviously the best results are obtained when the gray level image has a good contrast.

In our method, if the user wants to threshold the dark objects (or dark zones) in the image, then he/she must use the hmax operator; conversely, if the user wants to threshold the bright objects (or bright zones) in the image, then he/she must use the hmin operator. Commonly, it will be a good practice to consider either the dark or the bright objects, depending on the number of pixels of each class appearing more abundantly in the image.

When we apply the operator hmax to threshold the darkest objects in the image, the histogram of the *modified* image shifts to the left in the value h, according to Eq. (5), because all pixels of the original image is subtracted in the value h. For that reason, in the histogram of the *modified* image, obtained when the operator hmax is applied, a maximum gray level appears always in the value (255 – h). For this reason, maxima over this value in the histogram of the original image are not of importance. On the other hand, when we apply the operator hmin to threshold the brightest objects in the image, the histogram of the *modified* image shifts to the right in the value h, according to Eq. (6), because all pixels of the original image is added the value h. In it a maximum gray level appears always in the value h. For this reason, maxima below h in the histogram of the original image are not of importance.

The general methodology to select the most adequate threshold value for segmenting dark or bright objects from a gray level image using the hmax and hmin operators is the following:

1. From the histogram of the original image select the first relative maximum (from left to right in the histogram) as the value of h. Gray levels with the relative maxima having few pixels (less than 100 pixels in images with thousands of pixels, 0.05%) at the beginning of the histogram are excluded, because they do not contribute appreciably with a significant difference causing that the objects appear very scarce in the

resulting binary images. Also, the common maximum and minimum in levels 0 and 255 neither are used by our method.

2. For dark (bright) objects apply the operator hmax (hmin) to the original image to get a *modified* image.
3. From the histogram of the *modified* image select the eventually appropriate threshold values from the relative minima and apply them to the original image. If hmax was used, the minima to be selected are located nearest to the left part of the histogram of the *modified* image. If hmin was used, the minima to be selected are located nearest to the right part of the histogram of the *modified* image.
4. The results of the previous step may be many binary images, one for each minimum selected from the *modified* image, each with a given number of dark (bright) objects.

We consider heuristically the best threshold value the gray level which produces a binary image with more spatially independent (non-connected) objects together with a greater total amount of dark (or bright) object pixels.

The most problematic step in the methodology given above is the steps 3. If the user applies hmax (hmin) and he/she is going correspondently to threshold dark (bright) objects, then he/she must select the best grey level from all minima in the histogram of the *modified* image. To extract the adequate relative minima from the histogram of the *modified* image to the histogram was explored from left to right with a 41-pixel window. The window size of 41 demonstrated that is the best size in our practice for extracting the minimum

6 Results and Discussion

From the experiments carried out we will compare the resulting binary image obtained by the hmax(hmin) method with those obtained by other methods. Applying the method indicated above to the image in Fig. 1a (thresholding of the first type), the following results were obtained (Fig. 5 to Fig. 9).

Fig. 5 shows the original gray level image and its histogram. From the histogram, we can observe that the first relative (absolute in this case) maximum is located in gray level 59. This is the value of h (step 1). Due to the object to be segmented is bright we will apply to the original image the operator hmin. Then we obtain the *modified* hmin image shown in Fig. 6a (step 2). Figure 6b shows the histogram of the *modified* hmin image and Fig. 6c shows a fragment of the same histogram (zoomed) with an arrow indicating the first minimum, from right to left, at the gray level 99 (step 3).

Considering the gray level 99 as a threshold, when it is applied to the original image we obtain the binary image shown in Fig. 6d (step 4). Figure 8a shows the binary image obtained in the next minimum located in gray level Th = 143. Figure 7a shows the difference between the binary images shown in Fig. 6d and Fig. 7a. Undoubtedly, the quality of the segmented object resulting in Th = 99 is much better than that obtained in Th = 143. This demonstrates that the proposed method incorporates to the final segmented object some pixels from the diffuse edge between the bright and dark pixels on account of some dark pixels from the background. Similarly, we can asses that the use of the hmin method assure to select the threshold value in a more straightforward way than with a simple inspection.

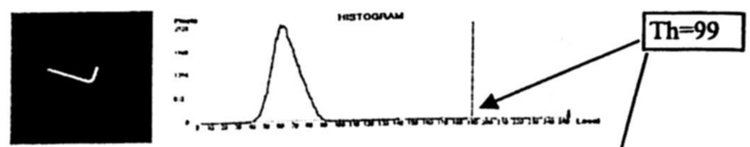
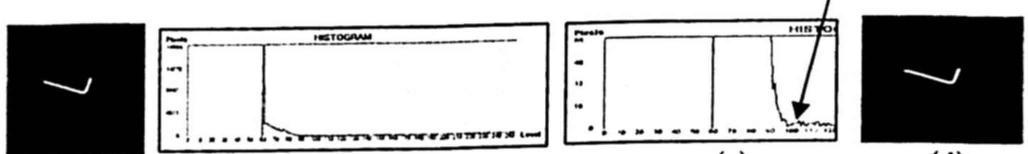


Fig. 5. Original gray level image and its corresponding histogram



(a) (b) (c) (d)

Fig. 6. (a) Hmin image; (b) Histogram of the *modified* hmin image; (c) Histogram zoomed (d) Binary image with Th = 99

(a) (b)

Fig. 7. (a) Binary image with threshold in Th = 143; (b) Difference between images in Fig.6d and 7a

Figure 8a shows the resulting binary image when the threshold Th = 99 is applied to the original image; Figure 8b shows the binary image obtained by the Otsu method [11]; Figure 8c shows the 55 pixels in excess obtained by the hmin(hmax) method when it is compared with the result obtained by the Otsu method. This demonstrate that the hmin(hmax) method described in this paper presents better efficiency, from the point of view of the number of total pixels in the minimum segmented objects, than the Otsu method. Taking into account the results obtained (more white pixels for the bright object), the hmin(hmax) method selects in each case a better threshold value in front of all other possible threshold.

(a) (b) (c)

Fig. 8. (a) Binary image obtained from the original thresholded in Th = 99; (b) Binary image obtained from the original thresholded by Otsu method; (c) Difference in excess (55 px) between (a) and (b)

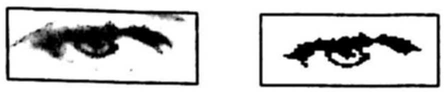


Fig. 9. Detail of the right eye of Lenna (pupil) segmented from the original image

Table 2. Some other results in images with dark objects having trimodal and multimodal histogram

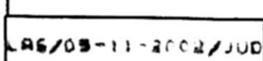
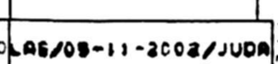
No.	Name	Original image	Binary image	(HMax) Mh; Th	Histogram Type
1	Runner (green plane)			mh = 61 Th = 166	TM
2	Runner (green plane)			Mh = 61 Th = 71	TM
3	Lenna (red plane)			Mh = 96 Th = 125	MM
4	Road			mh = 230 Th = 241	MM
5	Micro-text			MH = 85 Th = 170	BM

Table 2 shows other results obtained after the application of the operator hmax to detect dark or bright objects in gray level images having bimodal (BM), trimodal (TM) and multimodal (MM) histograms. Binary image 1 shows the fingers of the runners at the same time the wide white lines on the floor are shown. Image 2 shows only the shadow of the runner. Figure 9 shows a detail in the right eye of Lenna (the pupil) shown as the image 3, detected by the proposed method, with Mh = 96 and Th = 125. It is worth to note that the detection was achieved in the complete original image (not in the fragment shown). Image 4 shows the white objects found on the image of the road: the sky, four posts of the fence and the lines on the pavement. Finally, the binary image 5 shows clearly the holes in letters A and D, and in the number 0 (zero) in the image of the micro-text.

7 Advantages of the Method

The method, considered as one of local thresholding, has the following advantages:

1. Gray levels have an extended influence over neighbor pixels because all intermediate peaks (troughs) in the original image f are eliminated in a natural way by the reconstruction by dilation (erosion) of f from the $f-\mathrm{h}$ $(f+\mathrm{h})$ image. It produces a kind of plateau around all pixels that maintain the category of extrema.

2. In practice, thresholding by our method includes some of the pixels located throughout the natural ramp-shaped edge commonly created between two different gray levels, making possible to add more pixels to dark (bright) objects appearing in the original image.

3. Additive (either uniform or Gaussian) noise, intrinsically and frequently present in digital images, has less presence in the so called *modified* image. This produces more homogeneous gray level distribution, either related to objects or to the background, when the minima for thresholding are selected. For this reason, the quality of the final binary image is highly improved, that is, isolated objects with some few pixels do not appear in the final image as artifacts.

4. Because of the discrete nature in the selection of the threshold gray level, the thresholding has effect each time over a broader range of gray levels than with any other method used for thresholding.

5. Details of interest in the original images to be thresholded have less probability to be lost in the resulting binary image (See the pupil of Lenna in Fig. 9 and the holes of the micro-text image in Table 2). This is accomplished using as the threshold in the original image the gray level located as the first minimum in the *modified* hmax image located after the first maximum (from left to right in the histogram) used as h in the hmax operator and as the first minimum in the *modified* hmin image located before the first maximum ((from right to left in the histogram) used as h in the hmin operator.

6. It is achieved a higher selectivity (or discrimination) of the bright (dark) objects, since the thresholding is selected very easily (from less number of minima) on the modified images hmin (hmax), respectively (See the binary images 1 –runner- and the image 4 –road- in Table 2).

7. The quality of the original image (i. e. blurred) is not of great importance because it does not limit in any form to achieve good objects segmentation. It is possible to find in a relatively easy way the most suitable threshold value.

8 Conclusions

The new method proposed for thresholding to convert gray level images in binary images is based on intrinsic properties of the h-extrema hmax and hmin morphological operators. hmax is used to segment the dark objects and hmin to segment bright objects. Gray levels have a more extended influence over neighbor pixels because all intermediate peaks (troughs) in the original image f are eliminated in a natural way by the process of reconstruction by dilation (erosion) of f from the $f - \mathrm{h}$ ($f + \mathrm{h}$) image. In practice, the proposed thresholding method includes many pixels located throughout the natural ramp-shaped edge commonly present between adjacent regions having any two different gray levels. It proved also to be more immune to noise.

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