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Zero Crossing Edge Detection and Contour Tracing for Segmentation of Cervical Cell Nucleus

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ABSTRACT

To automate the process of screening of normal and abnormal cervical cells, there is a need for automatic segmentation of the nucleus of these cells. This paper presents an algorithm using the Laplacian of Gaussian operator and contour tracer to segment the nucleus from the background. The algorithm has been tested on different kinds of images of cervical cells.

1. INTRODUCTION

Cervical cancer is one of the most important cancer problems in the medical field. Due to its inherent nature, the cancer remains in latent state for a long period (10-15 years). If the patients are diagnosed during this period complete cure is possible. Hence, in many countries mass screening of female population is periodically carried out for early detection of cancer. Screening is mostly done through smear analysis by the cytologists and furth-- diagnosis carried on those found abnormal.

There are two critical problems associated with such screening. Firstly, nearly 95 per cent of the slides presented for screening would be normal with the remaining 5 per cent suspicious. Secondly, at the onset of the cancer, the smear shows some cells, known as mild dysplastic cells, which are rather difficult to identify visually.

In such a scenario, a system which can automatically classify the normal and suspicious slides is of great help for medical professionals, as they need to examine the suspicious slides for further diagnosis. In order to achieve the above objective, automatic segmentation of the cervical cell nucleus is absolutely necessary.

2. LOG ZERO CROSSING SEGMENTATION

Marr and Hilderth[1], and Huertas and Medioni[2] proposed a novel method for obtaining the edges in image. That is to convolve the image with an operator known as Laplacian of Gaussian (LOG), which is given by the expression:

$$\nabla^2 g(x,y) = \left(\frac{\quad}{\pi\sigma^2\sigma^2} \right) \left(\frac{x^2+y^2}{2\sigma^2} - 1 \right) \exp \left(\frac{x^2+y^2}{2\sigma^2} \right) \quad (1)$$

where $g(x,y)$ is a Gaussian function given by the expression:

$$g(x,y) = \left(\frac{\quad}{2\pi\sigma} \right) \exp \left(\frac{x^2+y^2}{2\sigma^2} \right) \quad (2)$$

The zero crossings (the locations where the convolved output changes sign) are obtained and used as the edges of the image. The LOG operator has some interesting features. The operator integrates to zero over the full domain. Though it extends to infinity in both dimensions and directions, it is insignificant after some distance which is dependent on σ. As such, in the discrete version the size of the mask is dependent on σ. The LOG operator is in a way classical unsharp masking operator, since the smoothed image central portion is subtracted from its periphery. Since the resultant zero crossings of the operator are of significance, the constant term is replaced by a convenient factor, suitable for integer operations, i.e., the whole mask will be a 2-D array of integers, for faster convolution operations.

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The contour tracing algorithm is designed which uses a routine called next pixel. This considers the 8 th neighbourhood of the pixel. The neighbourhood of the pixel is numbered as follows:

5	6	7
4	X	0
3	2	

The routine is initially called with a value 8, indicating that the contour tracing is initiated. In this case it will see all its neighbours for the occurrence of contour and returns the value when it first hits the contour, else it will return 8 indicating that it is an isolated point. The routine should be subsequently called with the value of previous occurrence at its next neighbourhood. In this case, the routine tries to find

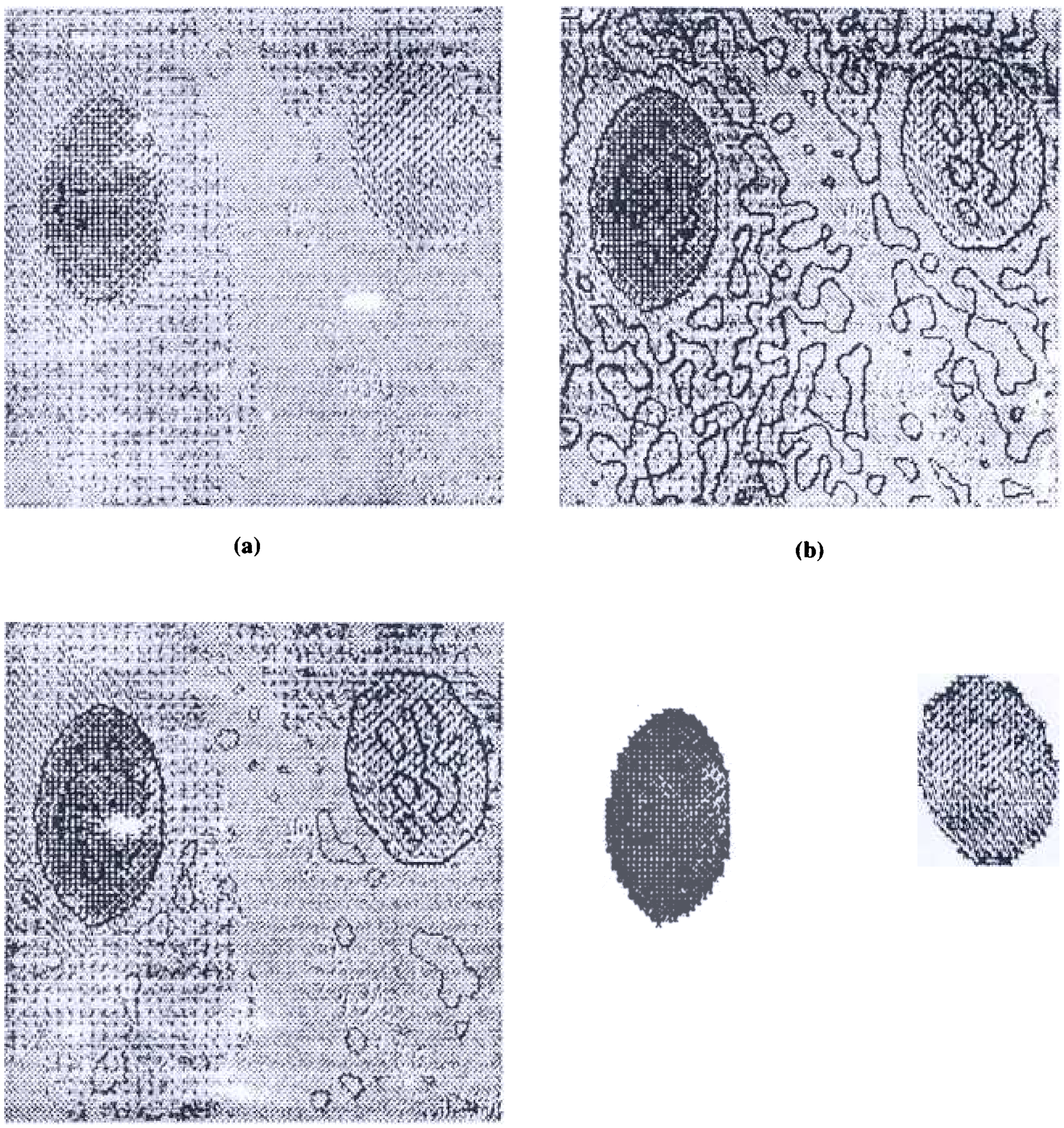


Figure 1. Cell image 5: (a) original image, (b) zero crossing at σ = 3.2, (c) closed contours, and (d) segmented image.

its occurrence in the neighbourhood first at 180°, followed by 135, 225, 90 and finally at 270 degrees. If it finds the occurrence it will return with appropriate value, else it returns 8 indicating that the contour has terminated.

The main routine will scan through the bit map of the zero crossings of the original image by calling this routine and at each time the image is traversed by the routine the pixel value is changed. If the next pixel returns 8 indicating the contour has terminated, that contour is removed from the bit map. If next pixel returns the location value which has been already traversed then it implies that the contour is closed. This contour is again traversed in order to remove the initial contour segment which is not the part of the contour which is then analysed for its area, perimeter, shape, and added into the list. This procedure is repeated for all the untraversed points in the bit map of the zero

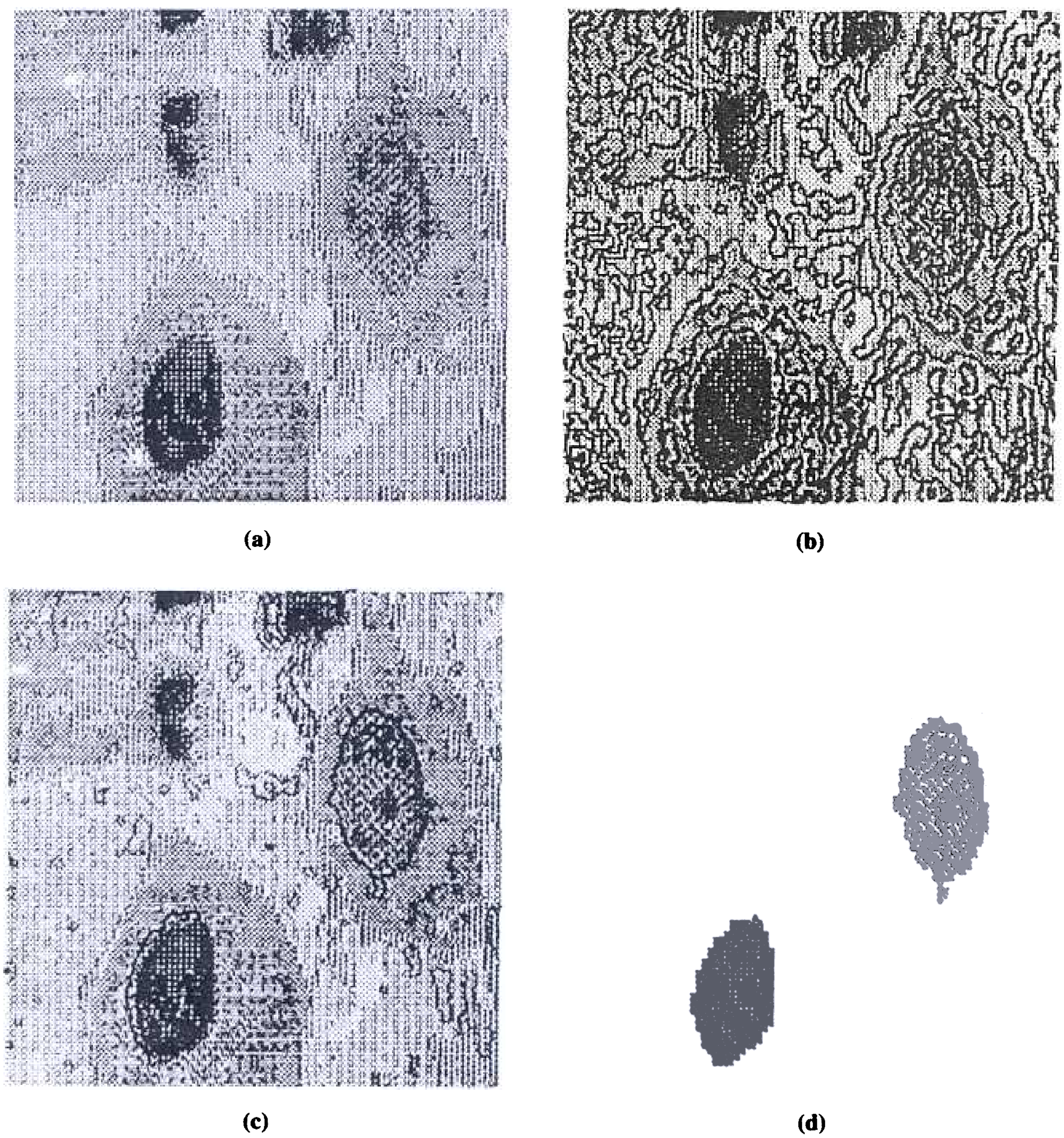


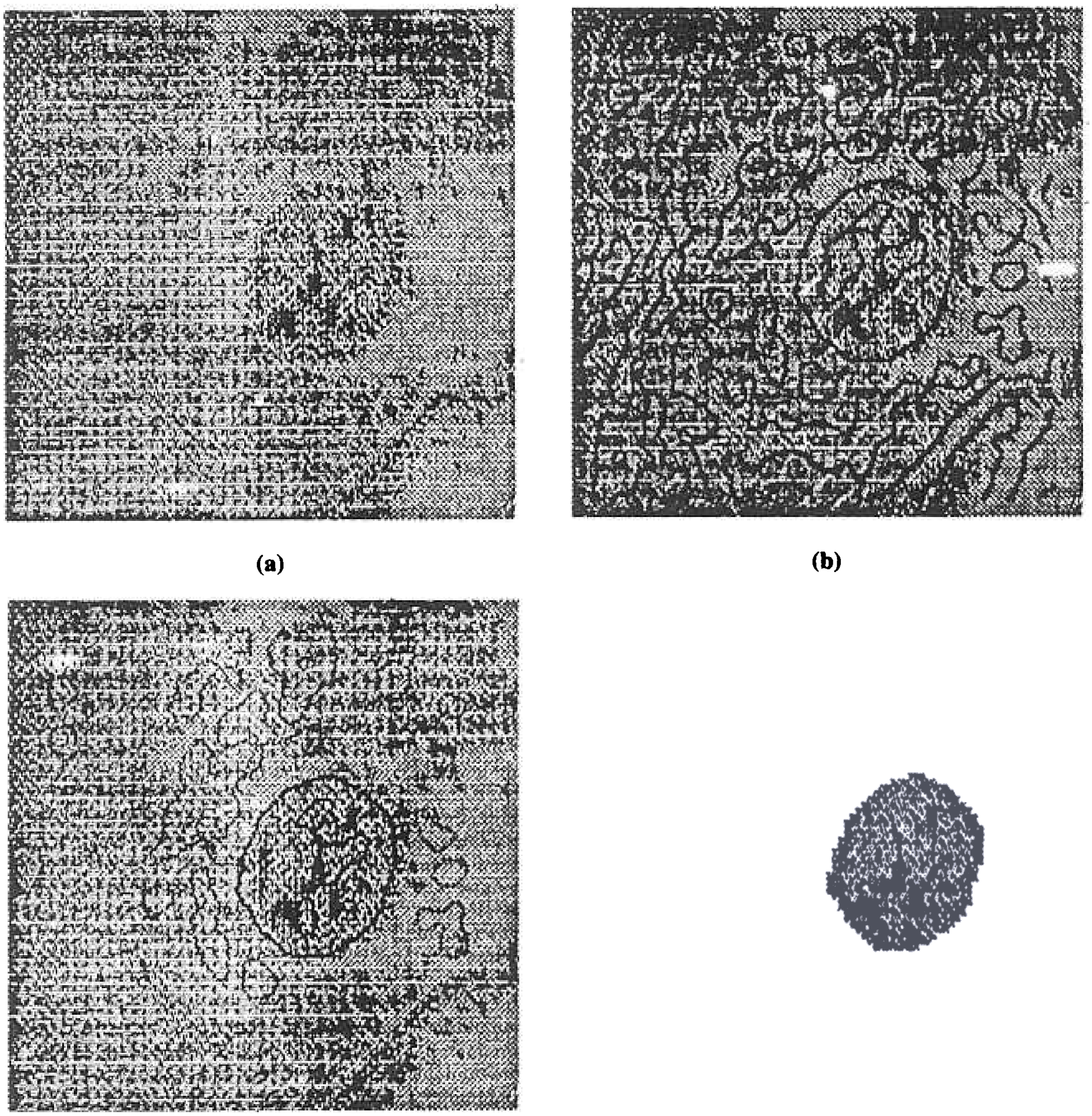
Figure 2. Cell image 1: (a) original image, (b) zero crossings at σ = 1.4, (c) closed contours, and (d) segmented image.

crossings of the image. Finally this will give a list of contours with its initial values (x_0, y_0), area and perimeter. This list is analysed for the contour of definite area and shape that corresponds to that of nucleus of cervical cells. The pseudo code of the algorithm is given in Appendix A.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experiment considered ten different kinds of images representing different situations—smears with excess of white blood cells, two nuclei at nearby distance, two nuclei where one of them has more contrast than other, etc—which are expected in a typical scan of cervical smears. LOG operator with different values of σ viz., 0.8, 1.0, 1.4($\sqrt{2}$), 1.6, 1.7($\sqrt{3}$), 2.0, 2.8($\sqrt{2}$), 3.0, 3.2, and 4.0 were used.

The results of the experiment for different images and different values of are shown in Figs 1, 2 and 3. Table 1 shows the overall performance of the algorithm



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

Figure 3. Cell image 7: (a) original image, (b) zero-crossing at σ = 4.0, (c) closed contours, and (d) segmented image.

Table 1. Results of zero crossing on 10 images for various values of σ

Image No.	No. of nucleus	4.0	3.2	3.0	2.8($2\sqrt{2}$)	2.0	1.7($\sqrt{3}$)	1.6	1.4($\sqrt{2}$)	1.0	0.8
1	2							1A	2	1A	
2	2		1A	1A	1A	1A	1A	1A	1A		
	1				1						
	2	1B	1B			1A	1A	1A	1A		
	2	1A	2	2	2	2	1B	1B	1B		
	1	1			1	1	1	1			
	1	1									
	1	1									
9	1										
10	1										

Note 1A indicates the left nucleus detected and 1B indicates the right nucleus detected out of two.

on ten images at different values of σ. Even when the whole image is clustered by the zero crossings at lower values of σ, the contour algorithm was able to pick up the nucleus contours. There was consistency of edges, and hence contours in different σ's. In certain images the nucleus contour was picked up by almost all the values of σ. In others it was picked up at fewer values of σ. It can be noted that at lower value of (0.8) there was no nucleus detected in any image.

The experiment shows that the LOG operator and its zero crossing can be used as an efficient tool in segmentation of nucleus in the automation of scanning the cervical smears. There are certain situations where the nucleus may be missed in all the values of σ (typically when the nucleus of several cells are overlapping). But such a situation is very rare in contrast to the situation when the cells are overlapping and the nuclei are isolated.

A more efficient algorithm can be devised for contour tracing to process all the contour pixel occurrences in the neighbourhood, since this algorithm gives the neighbouring pixel in some order of orientation and rejects the others. Also the bit maps of several (2, 3 or 4) zero crossings at different σ's can be 'and' ed and resulting bit map can be used for matching ellipse through Hough transform and nuclei can be obtained. Even though this is computationally intensive and time consuming, it can give the contours even when the nuclei are overlapping.

REFERENCES

1. Marr, D. & Hilderth, E. Theory of edge detection. *Proc. Royal Soc. London,* 1980, **207**, 187-217.
2. Huertas, A. & Medioni, G. Detection of intensity changes with sub pixel accuracy using Laplacian-Gaussian masks. *IEEE Trans. Pattern Analysis and Machine Intelligence,* 1986, **8**(5), 651-64.

APPENDIX A

Algorithm :

The pseudo code for the algorithm is as follows

```
repeat .
      select the next value of σ.
      determine the mask for that particular σ.
      convolve the mask over the image.
      get the zero crossings in horizontal direction.
      get the zero crossings in vertical direction.
      get the zero crossings in diagonal direction.
      find the logical or of all the zero crossings.
      form the bit map of zero crossings.

      repeat
            if the bit not set go to next location.
            else set initl. loc. to the point.
            enf if
            set next point = 8
            while (next point ≠ 8) or
            (next point not traversed)
                  traverse next point
```

end while

if next point = 8 remove the contour.

    else

        set initl. loc.

        while (next point not traversed)

        traverse next point.

        end while

        remove the contour.

        set initl. loc.

        find the maximum and minimum extensions.

        fill the inside of the contour.

        determine the area.

        set initl. loc.

        while (next point not traversed)

        traverse next point

        update perimeter.

        end while

        add to the list of contours

    end if

    (for all the points in the bit map)

    end repeat

    scan through the list and delete all the contours which has area > MIN-AREA.

scan through the list and delete all the contours which has perim*perim/4 π *area > 1.4 (odd shape).

form a new bit map of remaining contours with the internals of the contours filled.

using the new bit map segment the image.

(for all the σ values under consideration.)

end repeat