AUTOMATIC DETECTION OF FEATURES IN ULTRASOUND IMAGES OF THE EYE

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Outline

- Introduction
  - Problem definition
  - Parameters of interest
- The algorithm
- Results
- Conclusion

Introduction

- An automated technique is developed to analyze ultrasound images of the eye to measure Glaucoma angle

- This technique addresses the following challenges:
  - Denoising
  - Poor resolution
  - Poor contrast
  - Weak edge (boundary) delineation
  - Identification and feature extraction

Contributions

- Developed a complete algorithm to process ultrasound images of the eye
- The algorithm is tested on 80 images of the eye, 97% success rate is achieved
- Published papers:
  - 2 conference papers
  - 2 submitted journals

Publications

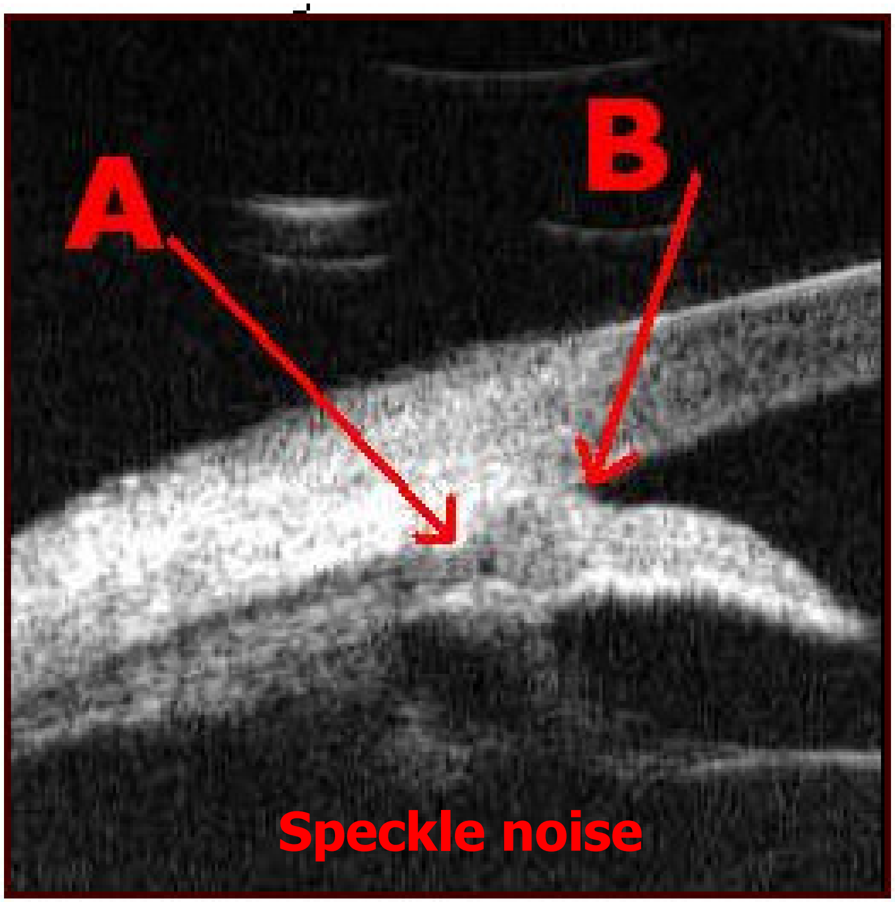
- Four publications:
  - Youmaran R, Dicorato P, Munger R, Hall T, Adler A (2005) Automatic Detection of Features in Ultrasound Images of the Eye, IEEE Instrumentation and Measurement Technology Conference, Ottawa, Canada
  - Youmaran R, Adler A (2004) Combining Regularization Frameworks for Image Deblurring: Optimization of Combined Hyper-parameters, Can. Conf. Electrical Computer Eng. (CCECE), Niagara Falls, Canada
  - Youmaran R, Dicorato P, Munger R, Hall T, Adler A (2005) Automatic Detection of Features in Ultrasound Images of the Eye, Transactions on Medical imaging, SUBMITTED
  - Youmaran R, Adler A (2004) Combining Regularization Frameworks for Image Deblurring: Optimization of Combined Hyper-parameters, Transactions on Image processing, SUBMITTED

Problem definition

- Glaucoma involves increased fluid pressure inside the eye, which damages the optic nerve and causes partial vision loss and can progress to blindness

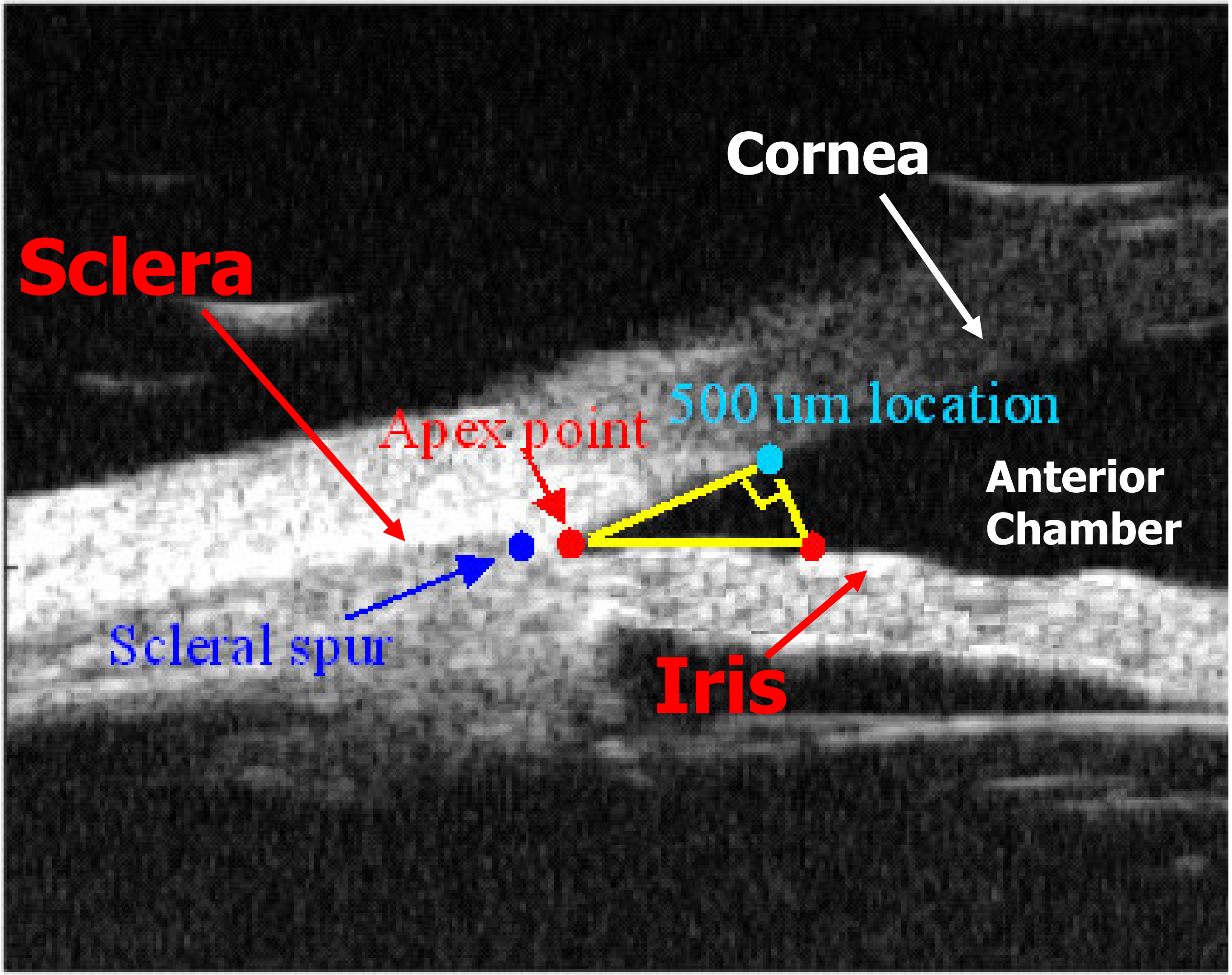
- Early detection of Glaucoma could prevent total loss of vision
  - Measure of closed-angle

Parameters of interest



Feature A: Scleral Spur
Feature B: Apex point

Features of interest



Ultrasound images of the eye

Open (normal)

Closed (diseased)

Intra-ocular pressure

THE ALGORITHM

Step 1

--- Coarse enhancement

--- Anterior chamber segmentation

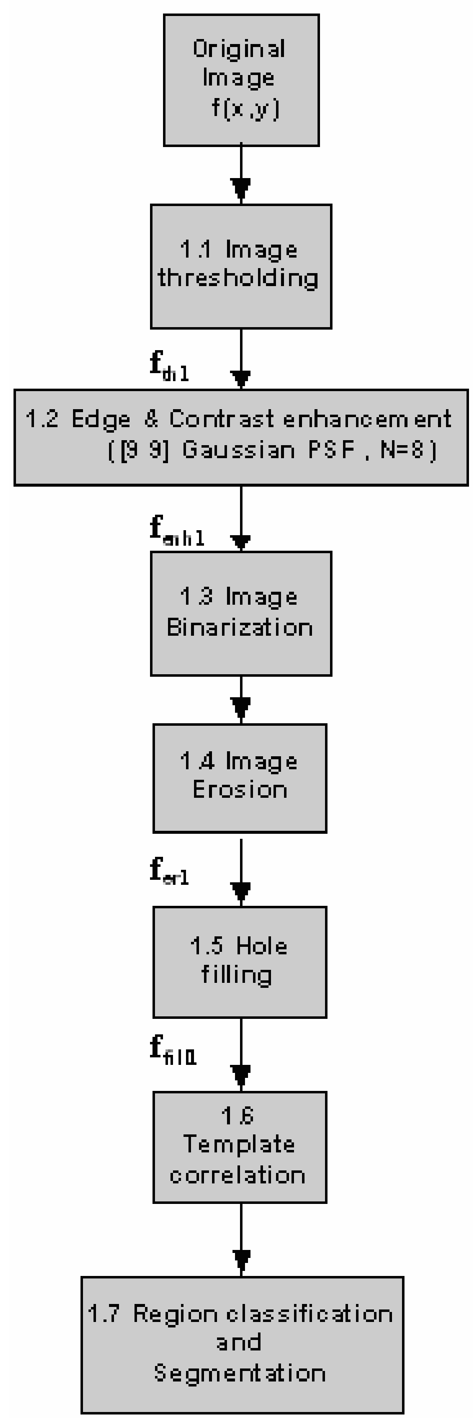
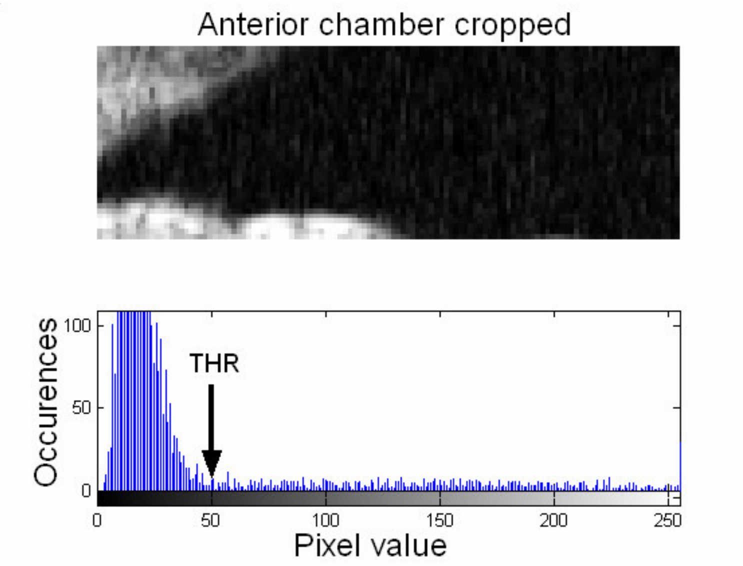
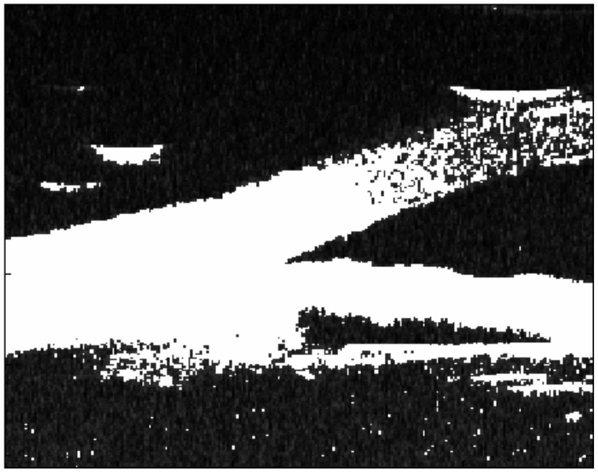


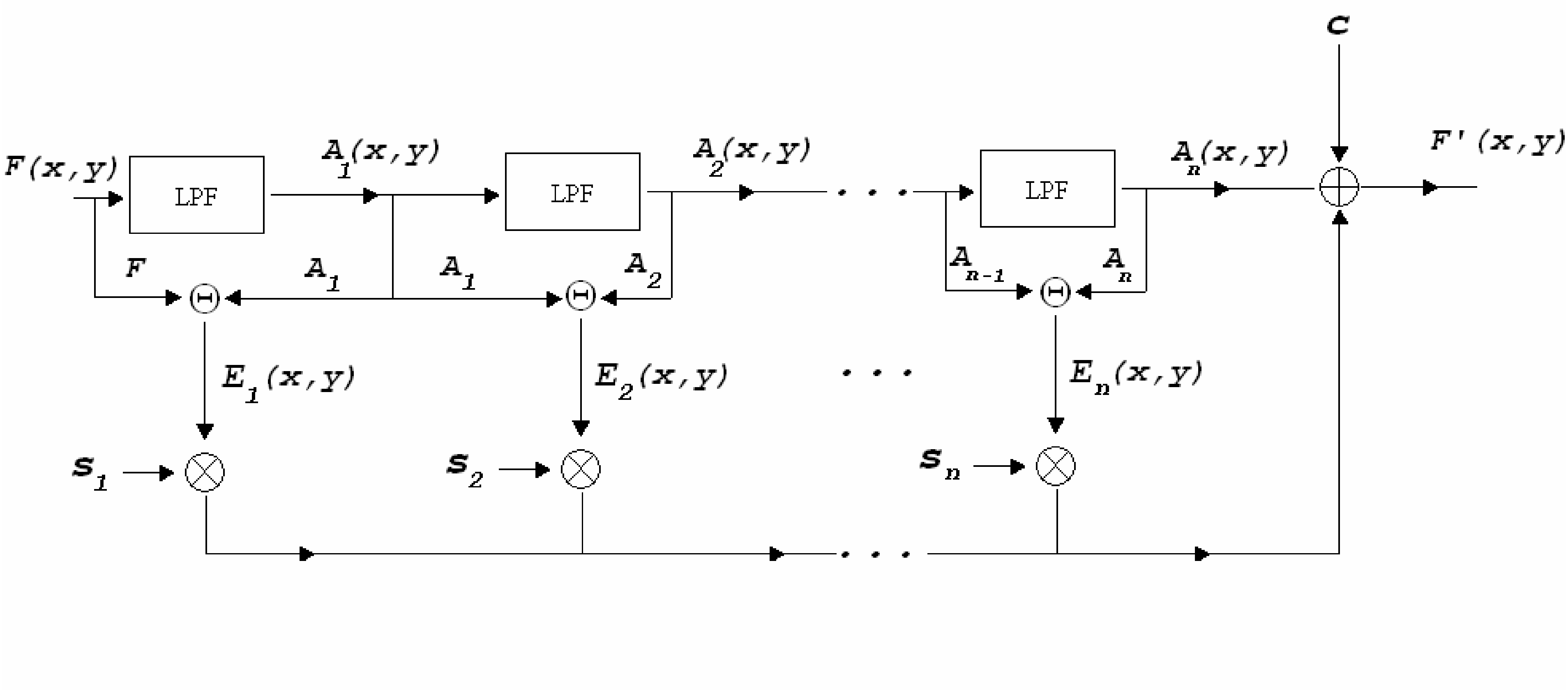
Image thresholding

- THR is selected based on a subset of images of the anterior chamber
- THR is selected at the tail of the histogram
- Pixels with intensity above THR are set to 255; otherwise, the value is unchanged

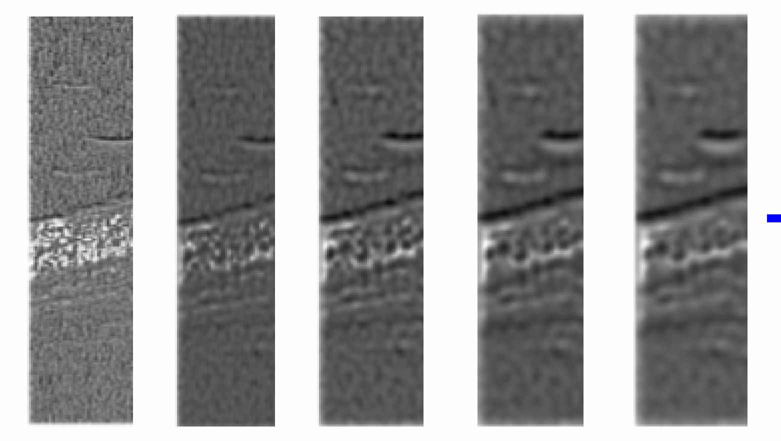




Multiscale Algorithm Block Diagram



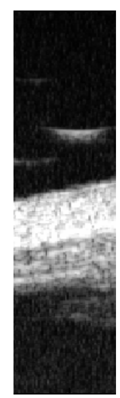
Effect of Multiscale processing



1st **2nd** **3rd** **4th** **5th**

Number of iterations

Original



(bad)

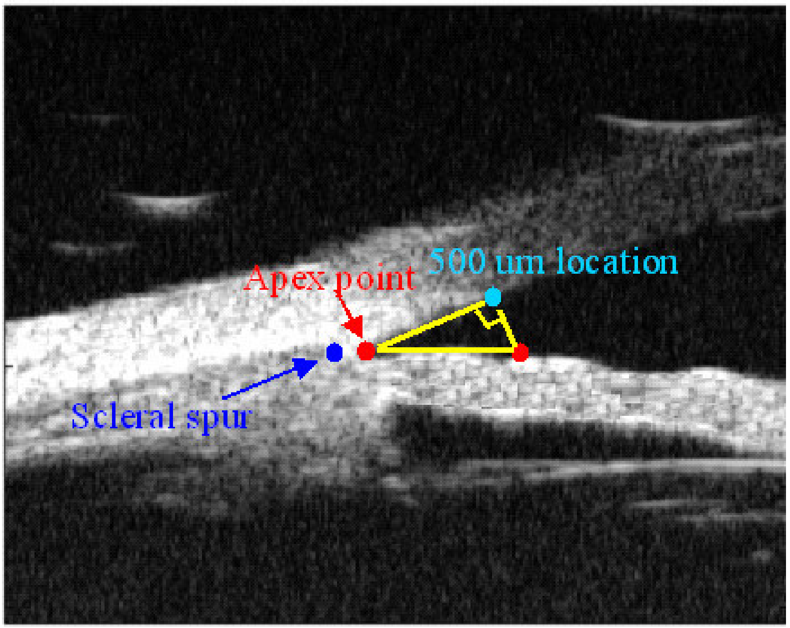
$s_i > 1$

(good)

$s_1, s_2, s_3 < 1$ and $s_4, s_5 > 1$

Denoising and enhancement

Non-Linear Edge & Contrast Enhancement



Original

Coarsely Enhanced

Template Correlation

- Correlation is used to locate the anterior chamber
- Template regions:

- Enhanced image is correlated with each template and the average correlation point is computed

Anterior Chamber Classification

- Each closed region is analyzed independently

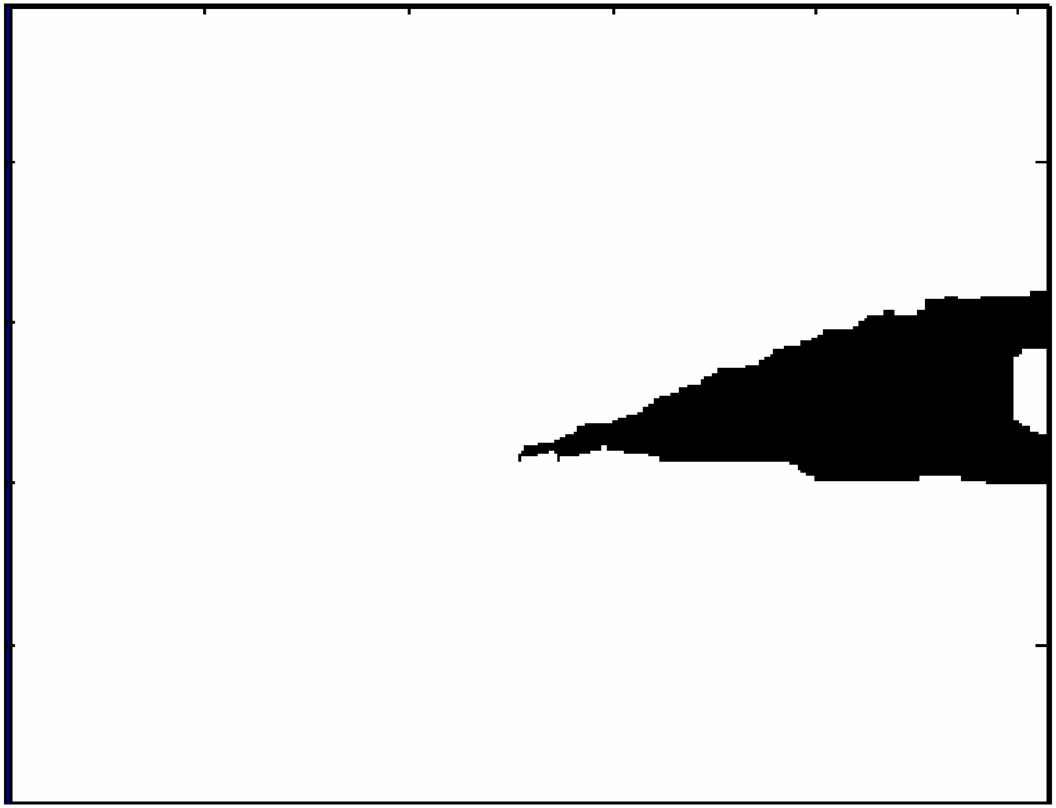
- Classification is based on the geometrical properties:
  - object area
  - Centroid
  - major-axis
  - minor-axis length

using an elliptical model

cont'd…

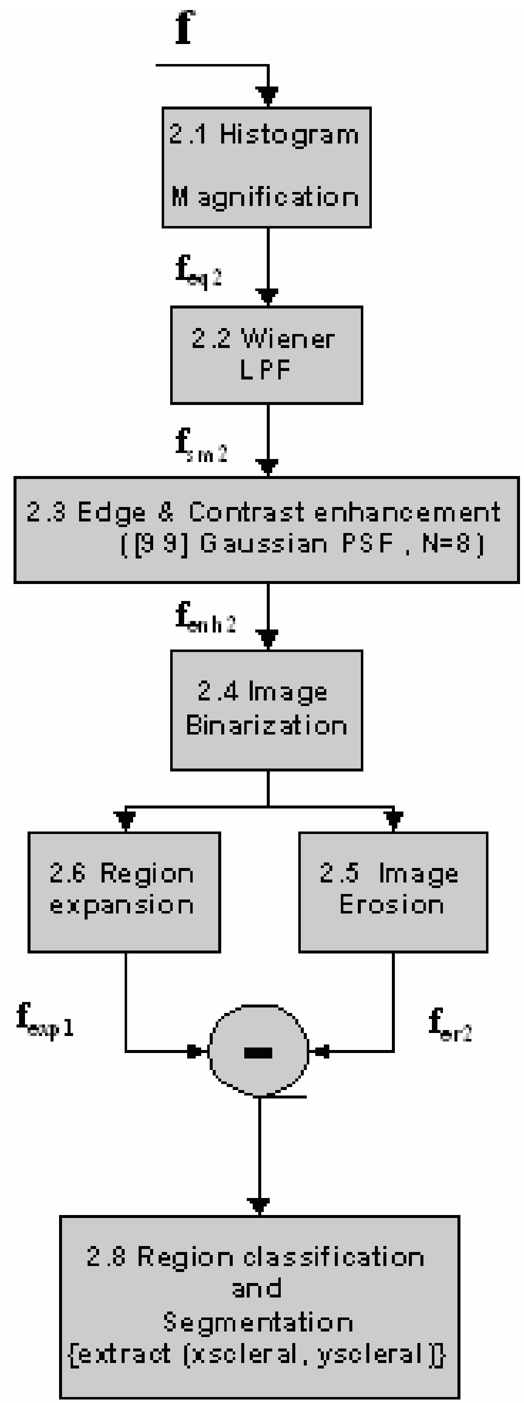
- The following parameters are computed for segmentation of the closed regions:
  - *Center*: Defined as the center coordinate of a region
  - *Distance center-correlation point:* **Must be minimized**
  - *Area:* Must be > 50 pixels, otherwise, the region is considered to be speckle noise

Anterior Chamber segmented



Step 2

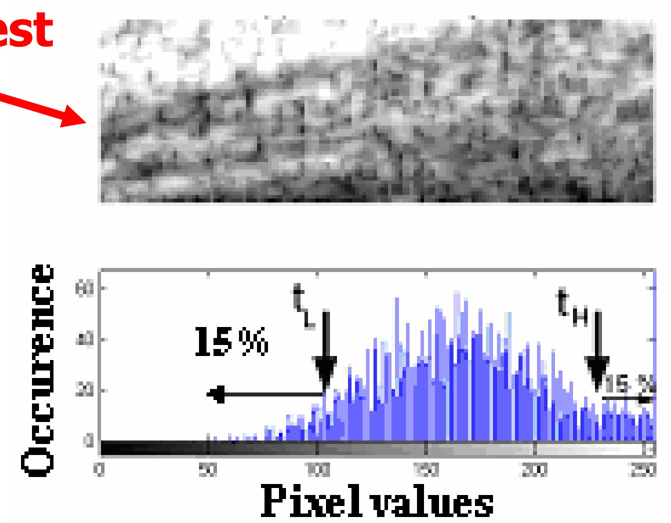
--- Fine enhancement
--- Sclera segmentation



Histogram magnification

- A histogram magnification: enhance texture of sclera
- Threshold values: 15% and 85% of the total number of pixels

Texture of interest



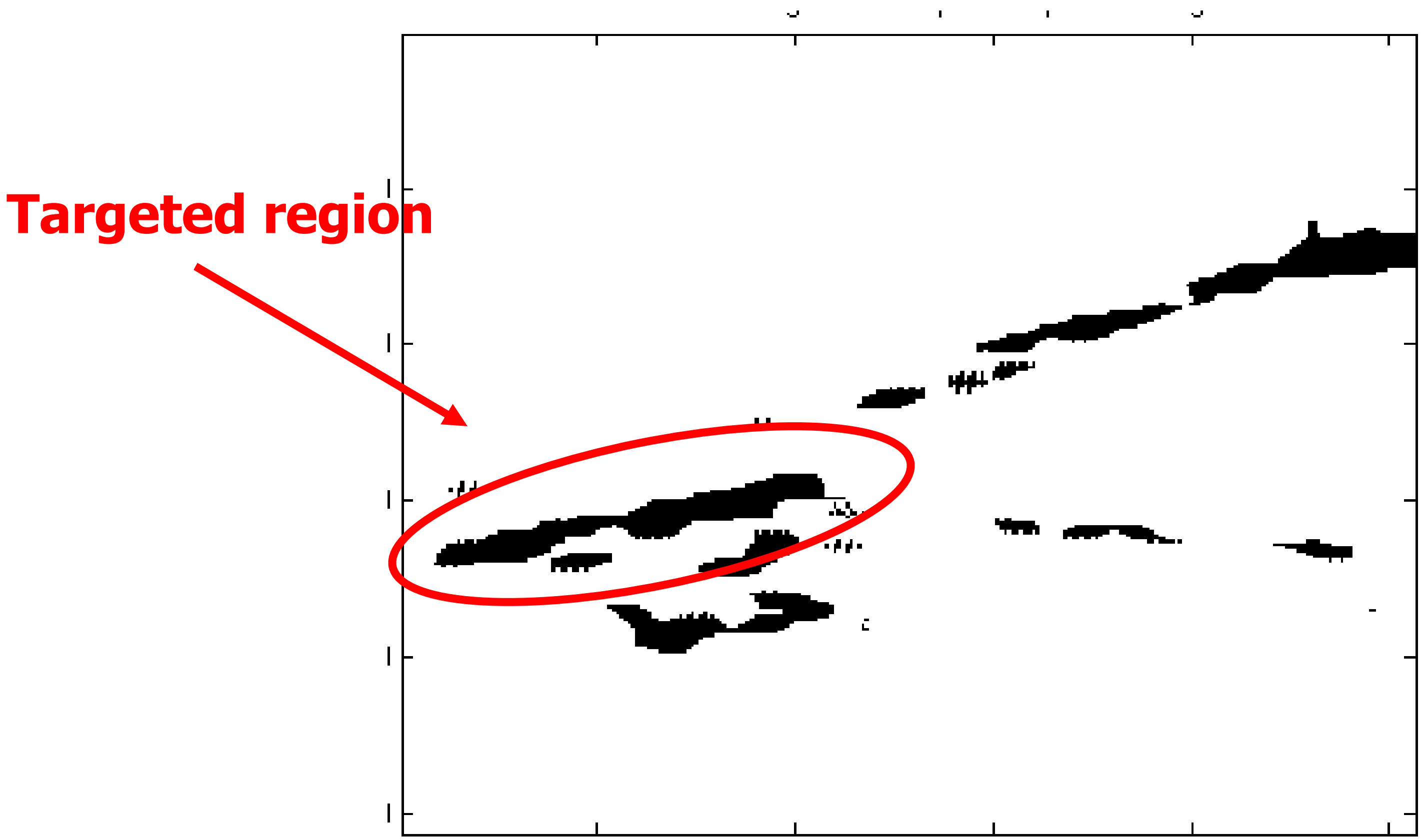
Noise reduction

- The image is filtered using an adaptive Wiener filter with a 9x9 pixel neighborhood

Enhancement result

Region Subtraction

- Removes all large regions and keeps only fine details



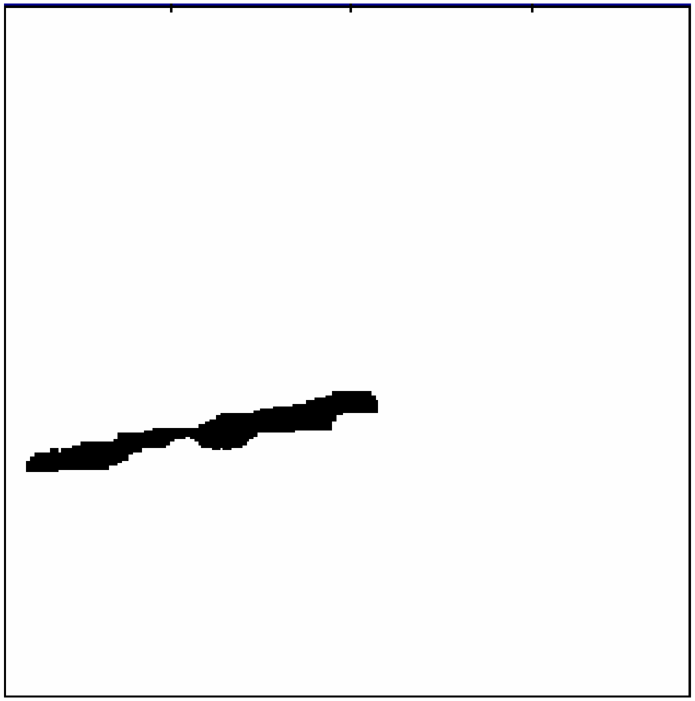
Sclera region classification and segmentation

- The following parameters are computed:

  (a) Right-most pixel of each closed region

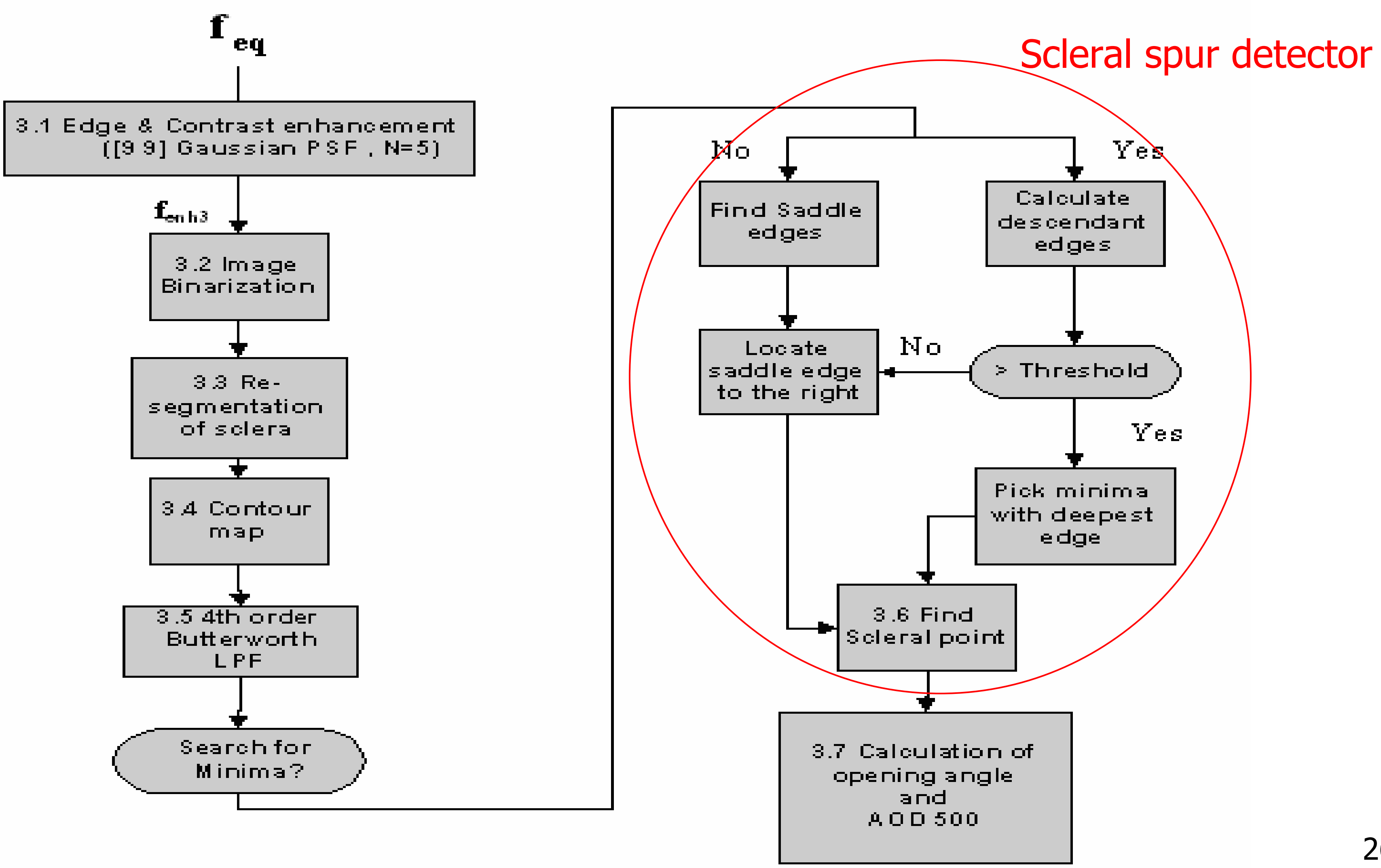
  (b) Distance from the apex point to the right-most pixel is computed:

  Must be minimized



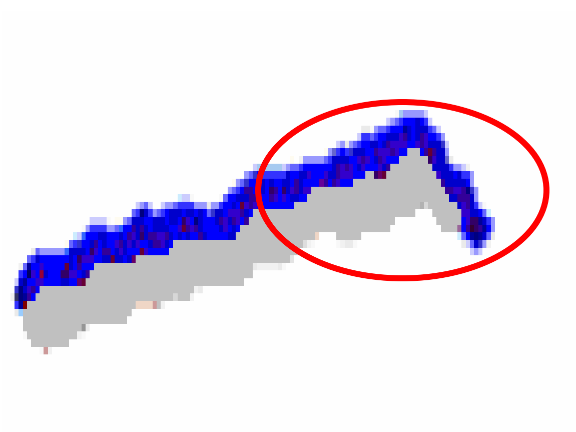
Step 3

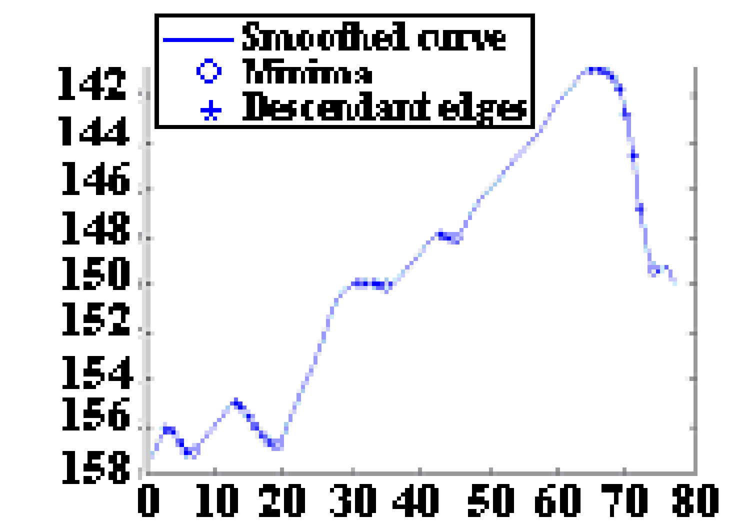
-- Extra fine enhancement
-- Sclera region re-segmentation



Sclera Contour Mapping

- 1-D signal plot of the contour
- Smoothing: Remove outliers and abrupt variations in the outline





Scleral Spur Detection

- The scleral spur is detected based on the following steps:

  (1) A gradient operator is applied on the smoothed contour

  (2) All minima coordinates & points along descendent edge prior to a minimum are computed

  (3) If no minima are detected, all points with zero gradient are located and defined as saddle edges

Scleral spur location

- Identification/detection of the scleral spur:

→ **One local minimum**: The scleral spur coordinate

→ **Multiple minima**: Calculate the magnitude Δ_{edge} of each edge prior to a minimum. The largest Δ_{edge} is chosen to compute the scleral spur coordinate

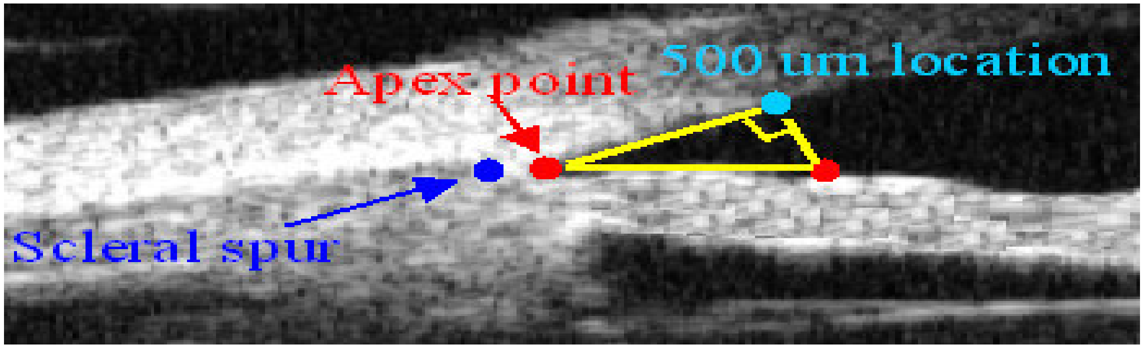
→ **No minima**: Select the saddle edge located most to the right of the 1-D outline

Determination of Measured Parameters

- Clinical parameters:

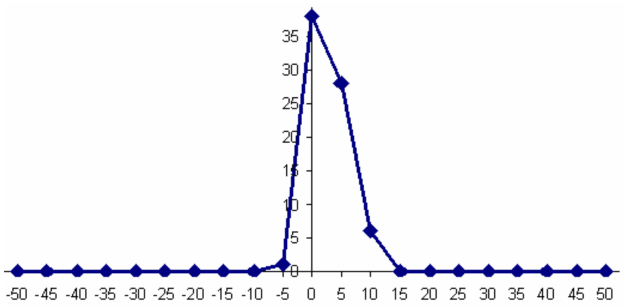
  (1) Open-angle exists if the 500 um point is located to the right of the Apex point

  (2) AOD 500: Through orthogonal projection from the trabecular-meshwork interface to the iris

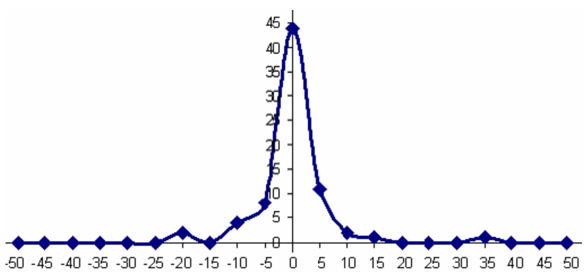


Outcomes of algorithm

Pixel offset error



Horizontal direction



Vertical direction

(1) Failure to segment regions

(2) Clinical parameters are computed and differ from those measured by the technologist within 97.5 um

(3) The offset error is greater than 97.5 um in either direction

Failure / Success rate

- On a sample of 80 images:
  - → Features were correctly identified in 97% of images (outcome 2)
  - → 3% of images presented inaccurate estimates (outcome 3) of the clinical parameters, with 351 um offset error on average

Conclusion

- We proposed an algorithm to automatically identify clinical features in ultrasound images of the eye
- The algorithm computes the AOD 500 and the open-angle parameters
- The algorithm predictions are very similar to the trained technologist's observation
- Success rate is approximately 97%

THANK YOU !

Some References

[1] Deng G., Cahill L.W., Image Enhancement Using the Log-ratio Approach, *Signals Systems and Computers*, Vol. 1, pp. 198-202, Nov1994

[2] Deng G., Cahill L.W, Multiscale image enhancement using the logarithmic image processing model, *Electronics Letters*, Vol.29, No.3, pp. 803-804, Apr1993

[3] J.S. Lim, Two-dimensional Signal and Image processing, Englewoods Cliffs, NJ: Prentice-Hall, pp. 536-540, 1990

[4] Daneshvar H., Brownstein S., Mintsioulis G., Chialant D., Punja K., Damji KF., Epithelial ingrowth following penetrating keratoplasty:A Clinical, Ultrasound Biomicroscopic and Histopathological Correlation, *Canadian Journal of Ophthalmology*, Vol. 35, No.4, pp. 222-224, Jun 2000

Image thresholding

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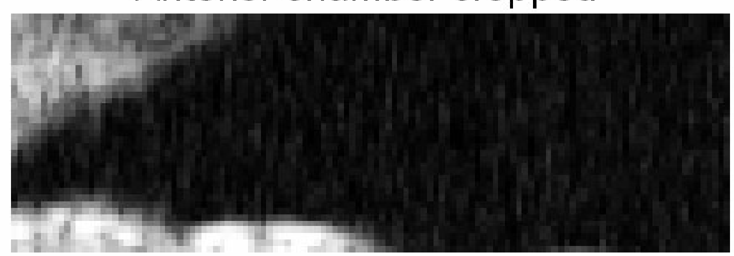
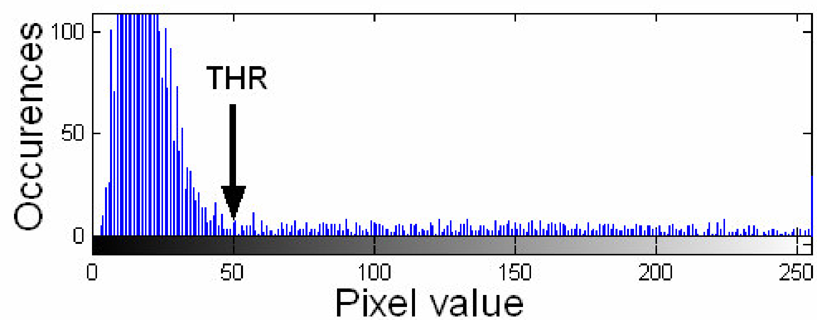
- Pixels with intensity above THR are set to 255; otherwise, the value is unchanged

Anterior chamber cropped





Why the Log-Ratio Approach?

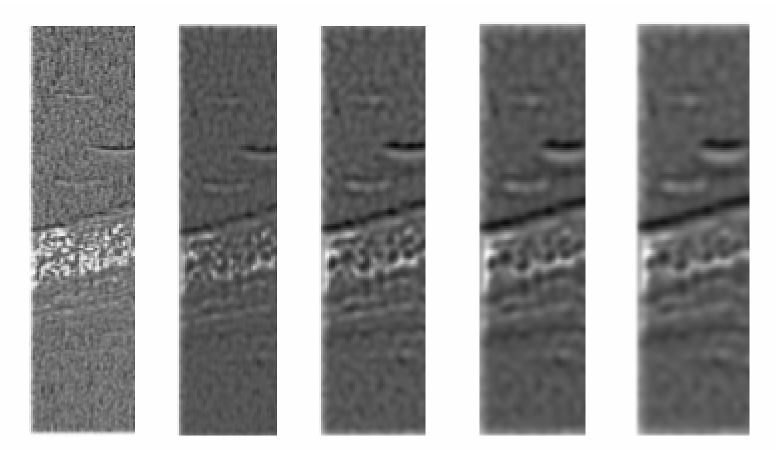
- Problems associated with image enhancement techniques:

  1^{st} problem: Out-of-range problem

  2^{nd} problem: Noise Amplification when Edge are enhanced

- Proposed Method interactively modifies contrast and edge sharpness in an image:
  - Logarithmic approach → 1^{st} problem
  - Multiscale approach → 2^{nd} problem

Effect of Multiscale processing



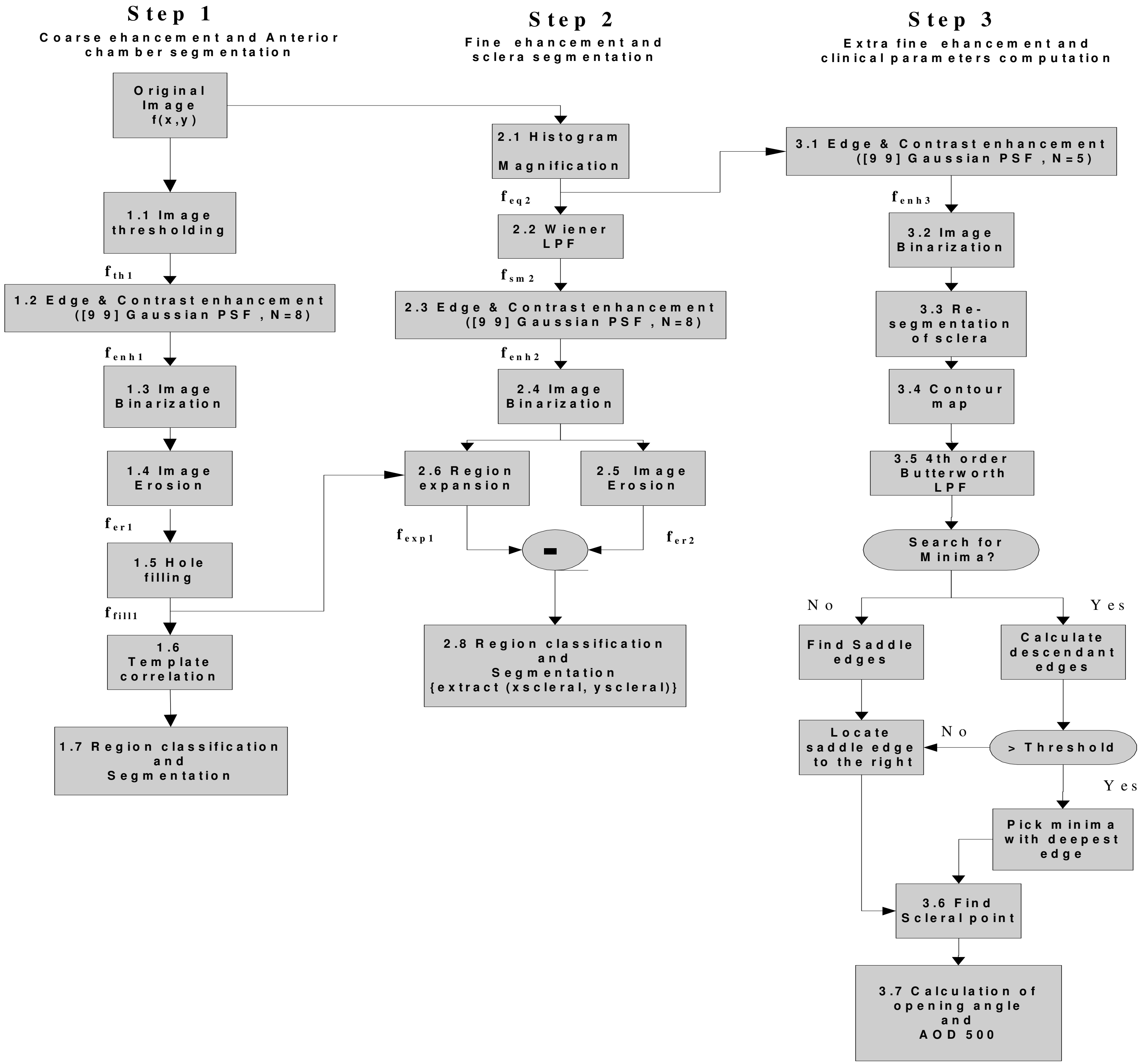
1st **2nd** **3rd** **4th** **5th**

Number of iterations

(bad)

(good)

Denoising and enhancement

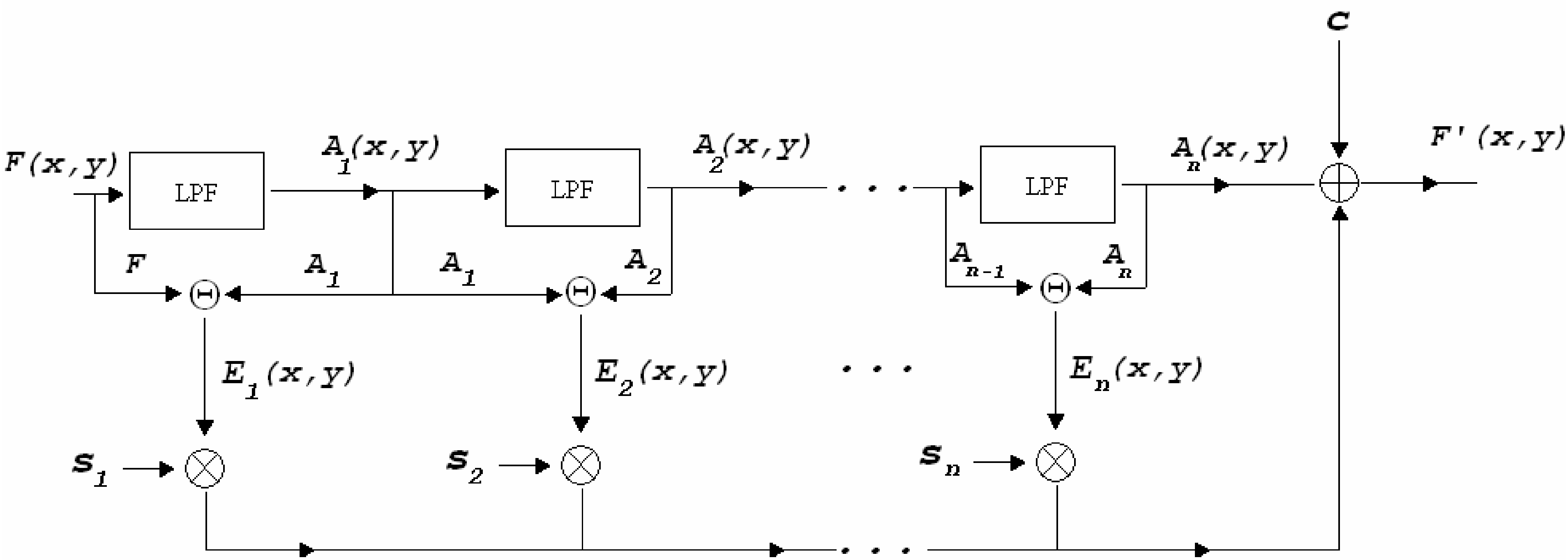

Step 1
Coarse ehancement and Anterior chamber segmentation
Original Image f(x,y)
1.1 Image thresholding
f th1
1.2 Edge & Contrast enhancement ([9 9] Gaussian PSF , N=8)
f enh1
1.3 Image Binarization
1.4 Image Erosion
f er1
1.5 Hole filling
f fill1
1.6 Template correlation
1.7 Region classification and Segmentation
Step 2
Fine ehancement and sclera segmentation
2.1 Histogram Magnification
f eq2
2.2 Wiener LPF
f sm2
2.3 Edge & Contrast enhancement ([9 9] Gaussian PSF , N=8)
f enh2
2.4 Image Binarization
2.6 Region expansion
2.5 Image Erosion
f exp1
f er2
-
2.8 Region classification and Segmentation {extract (xscleral, yscleral)}
Step 3
Extra fine ehancement and clinical parameters computation
3.1 Edge & Contrast enhancement ([9 9] Gaussian PSF , N=5)
f enh3
3.2 Image Binarization
3.3 Re-segmentation of sclera
3.4 Contour map
3.5 4th order Butterworth LPF
Search for Minima?
No
Yes
Find Saddle edges
Calculate descendant edges
Locate saddle edge to the right
No
> Threshold
Yes
Pick minima with deepest edge
3.6 Find Scleral point
3.7 Calculation of opening angle and AOD 500

Contrast--Edge enhancement equation

Proposed equation to interactively enhance contrast and sharpness:

$$F'(x,y) = \underbrace{A(x,y)}_{\substack{\textit{Smoothed}\\ \textit{version of}\\ \textit{F(x,y)}}} \oplus \overset{\substack{\textit{Controls Contrast}\\ \downarrow}}{c} \oplus \underbrace{\left[s \otimes \left(F(x,y)\,\Theta\, A(x,y)\right)\right]}_{\substack{\textit{Controls High spatial}\\ \textit{frequencies and}\\ \textit{sharpness}}}$$

Multiscale Algorithm Block Diagram



Wiener

$$u(\chi_i) = \frac{1}{NM} \sum_{x,y \in \chi_i} f(x, y)$$

$$\sigma^2(\chi_i) = \frac{1}{NM} \sum_{x,y \in \chi} \left(f(x, y) - u(\chi_i) \right)^2$$

$$\sigma_N^2 = \frac{1}{n} \sum_{i=1}^{n} \sigma^2(\chi_i)$$

$$H(x, y) = u + \frac{\sigma^2 - \sigma_N^2}{\sigma^2} \left(f(x, y) - u \right)$$