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Problems of Corneal Endothelial Image Binarization

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Abstract. In this paper we present two methods of binarization of corneal endothelial images. The binarization is a first step of advanced image analysis. Images of corneal endothelial obtained by the specular microscopy have a poor dynamic range and they are usually non-uniformly illuminated. The binarization endothelial images is not trivial. Two binarization algorithms are proposed. The output images are presented. The quality of algorithms is discussed.

Keywords: binarization, corneal endothelia, image processing.

1. Corneal endothelial images

Corneal endothelium is a monolayer of mainly hexagonal cells covering the posterior corneal surface. These cells are responsible for maintaining the corneal transparency dependent on the stable hydratation level (78%). Cells are closely joined "membrane to membrane" by zonulae occludens so there is no intracellular space; it allows to dehydrate the corneal stroma and epithelium. In human in contrary to many other species mitotic activity of endothelial cells is clinically insignificant so the cell number decreases continuously in the lifetime. The empty place left by necrotic cells is fulfilled by enlarging distorted neighboring cells. Every intervention in the anterior chamber space (surgery, trauma, etc.) as well as many congenital (PPD) and acquired diseases (e.g. glaucoma, diabetes) result in corneal cell number decrease. In the case of severe endothelial damage (cell density below 500 cells/mm^2) the remaining cells are no more able to enlarge and compensate the loss; water going freely by

simple diffusion from the aequs fluid stops to be removed that leads to irreversible corneal edema with consecutive transparency loss and functional blindness.

Specular microscopy allows to assess the endothelial layer in vivo – traditional parameters as corneal density (CD), coefficient of cell size variation (CV) and percentage of hexagonal cells (H) are not always sufficient in predicting the postsurgical corneal state, so many studies are conducted in search of additional cell features.

2. Medical image processing

Medical image processing is a wide area of researchers' interest. Correct image analysis is important in diagnosis and treatment effectiveness assessment. Endothelial images may contain important information about the corneal condition, impossible to achieve in the normal slit lamp examination [2]. The corneal endothelial images processing, binarization and segmentation were studied long time before [4]. The problem of processing and analyzing corneal endothelial images has already been discussed and the non-subsampled wavelet pyramid decomposition of lowpass region technique was proposed [3]. Also the directional filter bank was presented to isolate directional features in the endothelial cells image [1] and automatic recognition of different cell layers was introduced [5].

The problem of corneal endothelial images binarization is the first step to prepare these images for processing to determine factors that can easily describe an eye condition. Binarization should be as automatic and as precise as possible to give the best results and to provide source for factor calculations.

3. Binarization

Image binarization is a process which results in a binary image that consists of only two possible values, usually 0 (displayed as black) and 1 (white). Any color or gray images can be processed to obtain a two-level image. For bi-level images it is easier to write algorithms that find specific image features, like patterns, or to count interesting elements; usually binarization is a first step in image analysis. What is more bi-level images occupy the least amount of computer memory [6, 7].

Image binarization is not a trivial operation, because of source image distortions and noises. Techniques of binarization vary from simple threshold (Fig. 1b) to statistical algorithms or series of different image processing operations that may give more accurate results (Fig. 2c).

Quality of image binarization depends on the quality of the source image and its gray level dynamics that can be easily observed on the image histogram. The most

difficult case is when the interesting elements of the image are surrounded by the similar background and the image is non-uniformly illuminated [6].

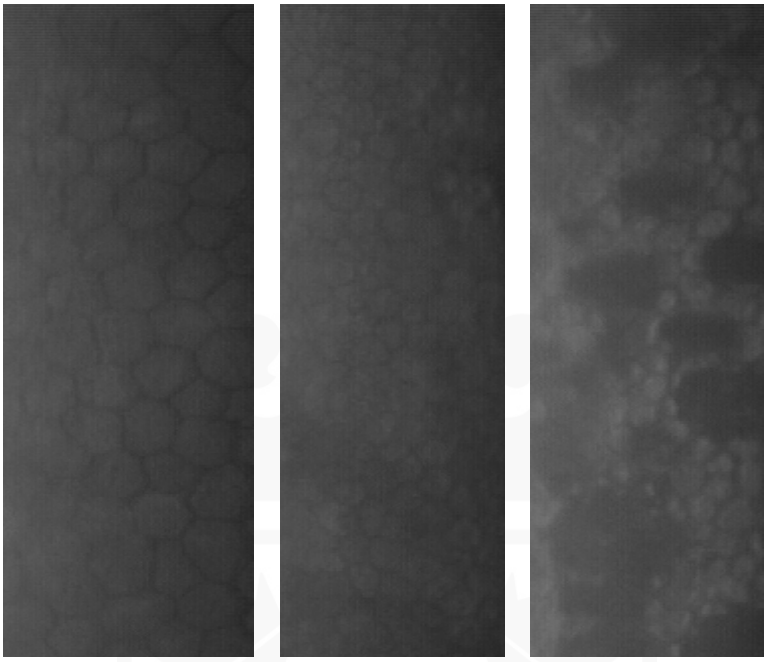
(a) (b) (c)

Fig. 1. An example of bad and good binarization. The source image has a low dynamic range (a) and auto threshold binarization gives poor results (b). The required effect is presented in the image (c)

4. Characteristics of the corneal endothelial images

Images of corneal endothelial obtained by the specular microscopy are 8 bit grayscale images (Fig. 2). The dynamic range is poor: only about 20–30% – between the most dark and the most bright data pixel are about 40–60 gray levels. What is more, images are usually non-uniformly illuminated (one side is noticeably brighter than the other), what has negative influence on the automatic binarization process (Fig. 3). Some other artifacts may appear near the image border that decrease usability of the parts of the image.

The cellular structures are usually well noticeable: brighter cells and darker boundaries. The sizes of the cells may vary (Fig. 2a and Fig. 2b). Some images also contain dark spots that indicate cell loss (Fig. 2c) and are important for diagnosis of corneal guttata connected with the higher risk of Fuchs dystrophy and postsurgical corneal decompensation.



(a) (b) (c)

Fig. 2. An example of images of corneal endothelial before any processing

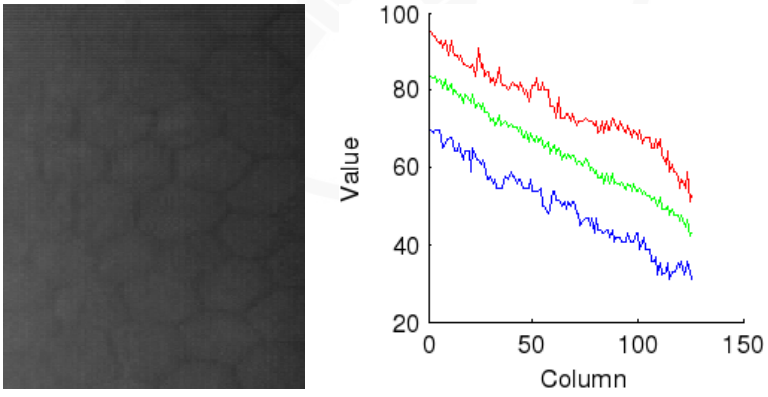


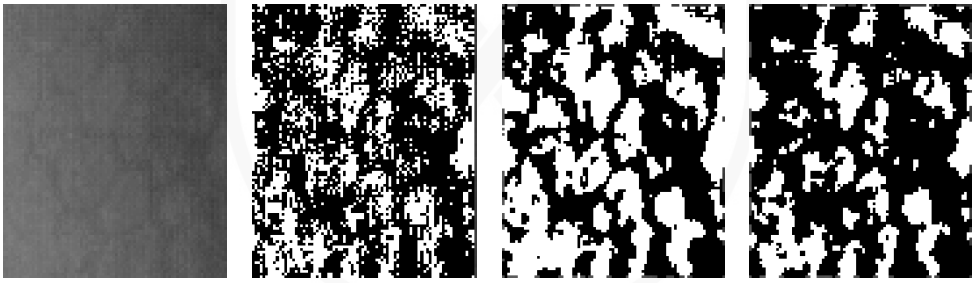
Fig. 3. Heterogeneous illumination of the corneal endothelial image with brightness graphs of maximum (red), mean (green) and minimum (blue) values for each column

5. Binarization of corneal endothelial images

The binarization is the first step of the corneal endothelial image analysis. It is important for further analysis of cells size, shape and density. Two binarization algorithms are going to be presented.

5.1. The adaptive binarization algorithm

The first binarization method – the adaptive algorithm – processes the image in fragments. The size of the fragment – the square box – is about 150% of the cell size and has to be chosen arbitrary. In every fragment maximum, minimum and average of the brightness is calculated. Then binarization is performed for each square, according to the selected threshold, which is equal to the calculated average or is a value between minimum and maximum brightness of the fragment as a selected percentage part of that distance. The last step is the median filter [6] done with the 3×3 square element. The median filter removes small artifacts and smoothes cells. The results of the binarization are presented in Fig. 4.



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

Fig. 4. Adaptive binarization results. The source image (a) processed without the median filter (b), with the median filter and the 55% (c) and 60% threshold

The presented binarization algorithm is not satisfying. The threshold selected as an average brightness of the fragment gives very poor results. Calculating the distance between the minimum and maximum value has also failed. The boundaries are misplaced as well as cells are not clearly extracted. The final bi-level image consists of significant artifacts that may have the negative influence on the further calculation.

5.2. The filter based binarization algorithm

The algorithm begins with histogram equalization [6]: the darkest source pixels becomes black and the brightest – white (Fig. 5). Then the high pass filter [6] is applied to remove low frequency, just like the heterogamous illumination. The threshold for this filter should be selected experimentally. Then binarization may be performed globally with the threshold equal to 128. The median filter is applied to reduce noise and artifacts. The final step is to remove elements that consist of the small number of pixels. This may be done by counting the pixels in consistent groups or by performing another median filter and calculating its intersection with the image before that median filter operation.

The results of this algorithm are better than the adaptive filter, but still include some artifacts. Their influence may also cause problems in further calculations.

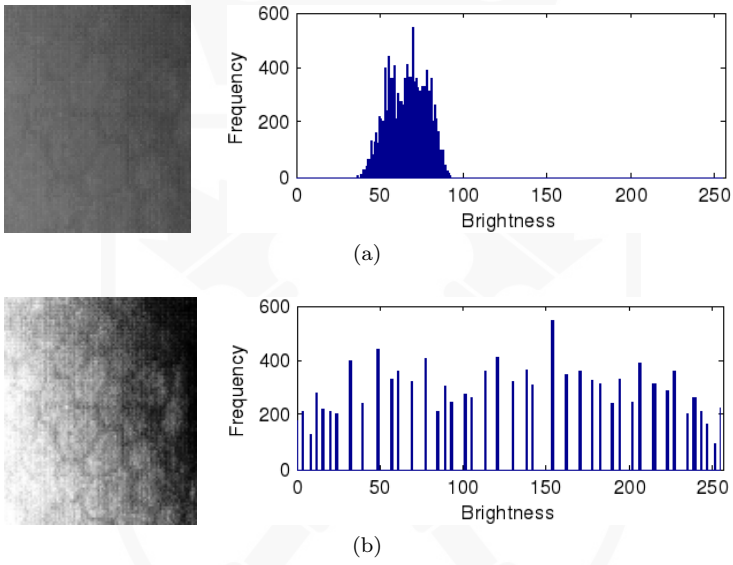


Fig. 5. Histogram equalization results (b) of the example image (a) with corresponding histograms

6. Results and conclusion

In this paper binarization of corneal endothelial images was discussed. It is the first step in creating software to perform analysis of corneal endothelial and to determine new parameters that will help in diagnosis and treatment effectiveness assessment.

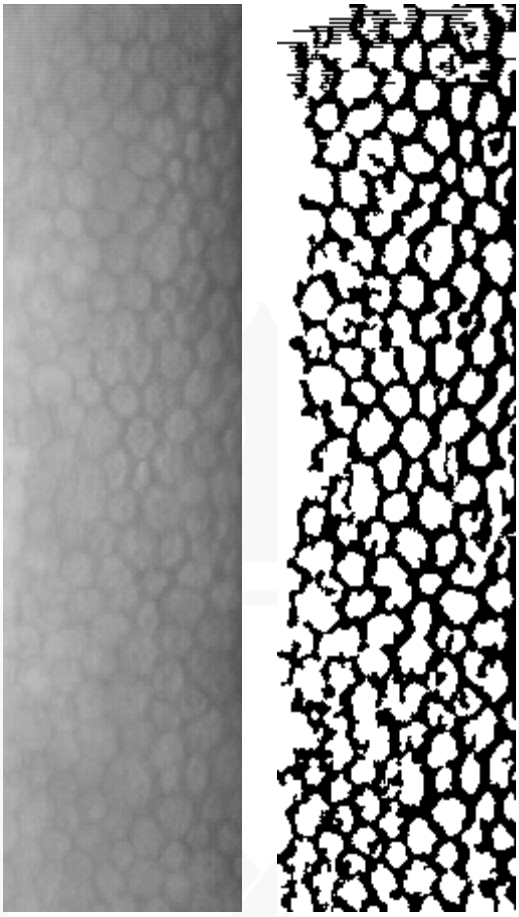


Fig. 6. Filter based binarization algorithm results. The source image on the left

Two algorithms and their results were presented: the first adaptive algorithm, suggested by non-uniform illumination, gives poor results, which is contrary to the expectations. The second filter based algorithm provides better binarization. In spite of its complicity, the filter approach may be a good solution for further analysis. Further work is to find new useful for ophthalmology parameters of corneal endothelial images.

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