Vision-Based Magnification of Corneal Endothelium Frames

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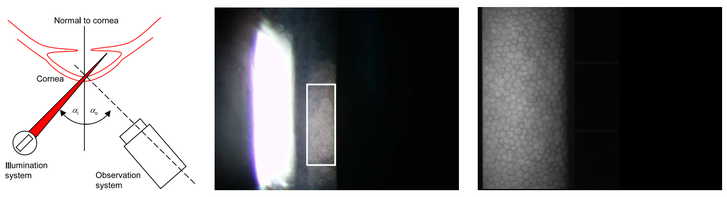
Overview

Objective — To compute a high-resolution (confocal quality) image of the corneal endothelium from a low-resolution video sequence obtained with a general purpose biomicroscope.

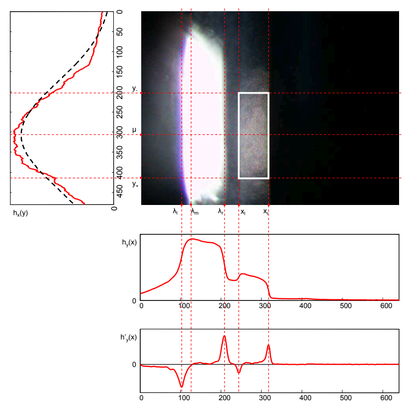


Approach

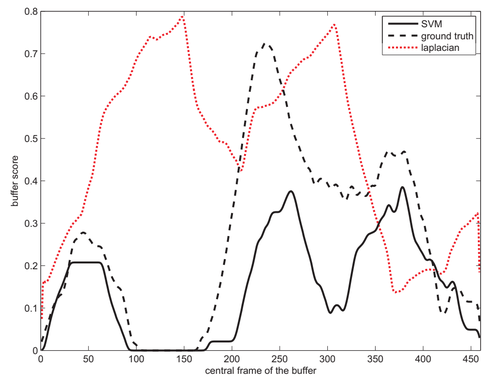
1. Automatic segmentation of the visible endothelium within each frame;
2. Selection of the best quality endothelium subsequence;
3. Image alignment and mosaicing of the selected visible endothelium segments;
4. High-resolution image generation by using all the pixels from the aligned images.

Data selection

A rectangular region enclosing the endothelium region is segmented by analyzing the shape and slope of cumulative horizontal and vertical histograms of pixel intensity.



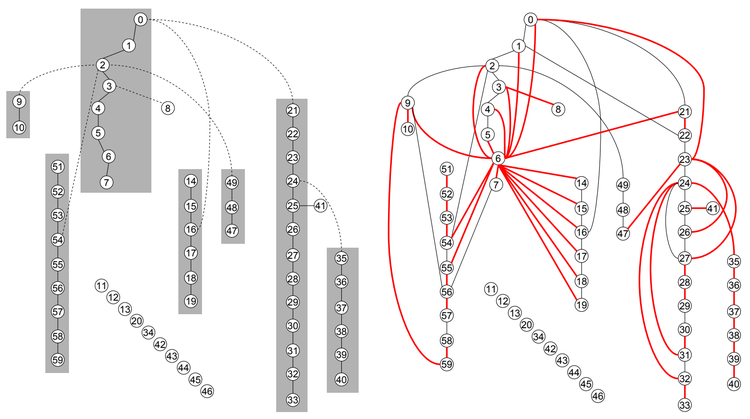
A quality measurement is required in order to select the best images to be used. For this purpose, SVM-based classification is combined with Laplacian-based ranking. These methods are complementary. On the one hand, SVMs can discriminate between segments with endothelial content and images where the endothelium is absent, but cannot provide any quality ranking among the images within the same class. On the other hand, the Laplacian operator is a powerful sharpness indicator, but is unreliable when applied to images without endothelium.



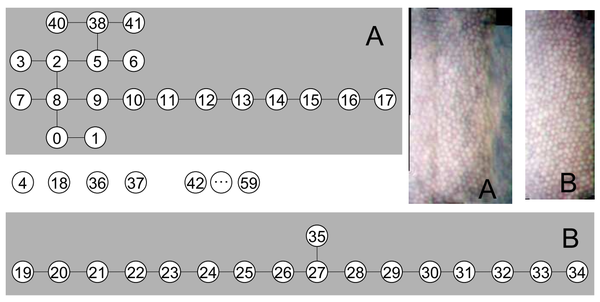
A subsequence of 60 good consecutive frames (2 sec of video) is used to obtain the HR image. The best SVM performance is obtained by using just two labels, "useful" and "not useful", and concatenating the CLD (Color Layout), CSD (Color Structure) and HTD (Homogeneous Texture) MPEG-7 descriptors.

Frame mosaicing

A robust, graph-based technique is used to align the frames of the selected 60-frame subsequence. A first, raw alignment based on affine transformations is carried out, producing several distinct chains of linked images. Each chain is a tree composed by a set of subsequent image nodes. Chains are then merged together to build wider trees.



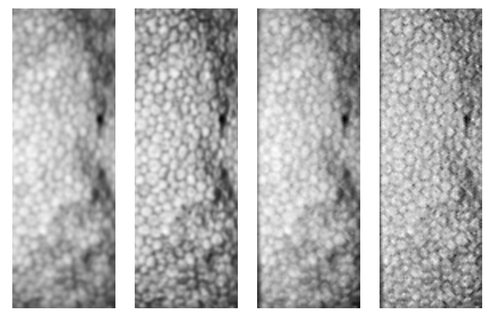
Multiple trees arise when it is not possible to merge all the chains in a unique connected graph. When this happens, each tree corresponds to a different mosaic, one of which is chosen to produce the HR image. By default the selected tree is the largest, unless a second one has a better average quality.



A finer image alignment process then starts. For this purpose, a node is selected as root, and acts as the reference frame of an image mosaic based on full projective warping transformations (2D homographies).

The HR image

The HR image is a magnified version of the reference frame. It can be recovered in closed form as a linear combination of several pixels coming from the LR images. The transformation $\mathtt{W}_k$ mapping the HR image onto each LR image I_k is $\mathtt{W}_k = \mathrm{diag}(\rho^{-1}, \rho^{-1}, 1)\mathtt{H}_k^{-1}$, where $\rho > 1$ is the magnification factor and $\mathtt{H}_k$ is the homography mapping I_k onto the reference frame.



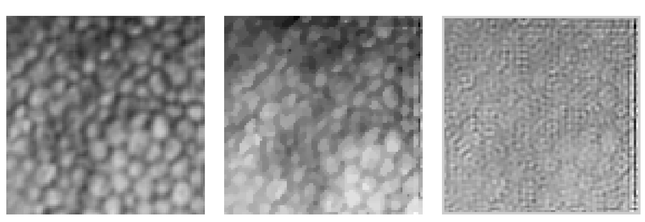
This method is better than using image interpolation, in which case non-realistic high-frequency image artifacts would arise.

Results

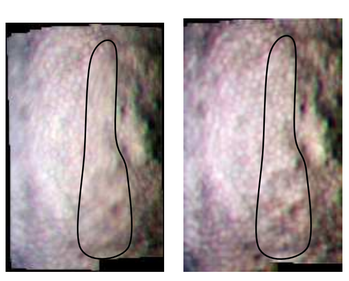
MPEG-7 descriptors	validation	runtime
CLD	76.08%	70.86%
CSD	92.11%	82.61%
SCD	80.86%	83.30%
EHD	87.80%	82.89%
HTD	89.47%	88.87%
CLD+CSD	89.71%	89.16%
CLD+SCD	80.62%	80.32%
CLD+EHD	88.28%	81.36%
CLD+HTD	90.19%	84.83%
CSD+SCD	90.19%	80.51%
CSD+EHD	89.47%	88.12%
CSD+HTD	91.39%	89.91%
SCD+EHD	90.19%	88.01%
SCD+HTD	90.67%	88.20%
EHD+HTD	91.63%	84.23%
CLD+CSD+SCD	89.00%	88.25%
CLD+CSD+EHD	90.67%	86.56%
CLD+CSD+HTD	**92.58%**	**91.86%**
CLD+EHD+HTD	88.73%	85.61%
CSD+SCD+HTD	**92.82%**	**90.58%**
CSD+EHD+HTD	91.39%	88.59%
SCD+CLD+EHD	87.61%	86.12%
SCD+EHD+HTD	91.63%	87.58%
CLD+CSD+SCD+EHD	90.67%	88.16%
CLD+CSD+EHD+HTD	89.87%	87.01%
CLD+SCD+EHD+HTD	90.01%	88.72%
CLD+CSD+SCD+HTD	**92.34%**	**91.16%**
CSD+SCD+EHD+HTD	91.13%	88.76%
CLD+CSD+SCD+EHD+HTD	91.63%	88.51%

SVM-based classification

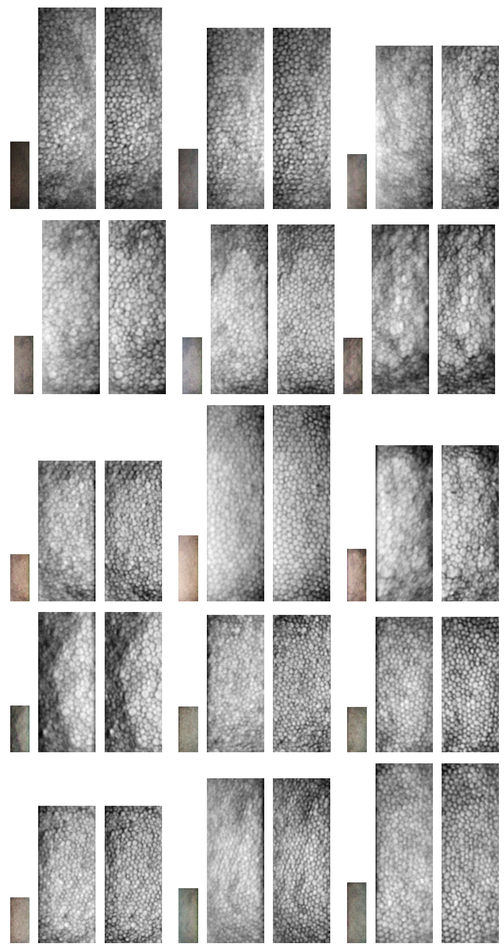
Laplacian-based ranking



Comparison of HR images: Our approach (*left*) vs MAP/Huber (*middle*) and MLE (*right*)



Comparison of mosaic images: A state-of-the-art method (*left*) vs our approach (*right*)



Gallery (magnification factor: 3×). For each triplet: original endothelium (*left*), bicubic interpolation (*middle*) and our approach (*right*)