INTERFEROMETRIC VIDEO ANALYSIS FOR PRELENS TEAR FILM SURFACE RECONSTRUCTION OF THE HUMAN EYE

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ABSTRACT

The study of tear film thickness of human eyes has important implications for understanding tear physiology and dynamics. In this work, we aim to develop a system of automated, robust and accurate methods that derive the tear film thickness on the surface of contact lenses in human eyes from a sequence of narrowband interferometric image frames and reconstruct the thinning surfaces of the tear film over time. The proposed system comprises four steps. Firstly, the video is stabilized to remove rapid and jerky eye movements, saccades, and image frames are aligned for accurate modeling of prelens tear film thinning dynamics. Secondly, the dry regions where the tear film breaks up and is zero in thickness are detected and separated using a texture based segmentation method. These dry regions not only indicate the dehydration rate of the prelens tear film, but are necessary to reconstruct the absolute thickness of the remaining wet regions in the tear film. Thirdly, images are filtered to suppress slowly varying background illumination and normalize fringe amplitude such that the following phase demodulation will be simplified with better results. Lastly and most importantly, the phase of interferometric fringe pattern is demodulated to infer the absolute thickness of the prelens tear film and recover its surface.

This work introduces a new feature extraction method named Resilient Subclass Discriminant Analysis (RSDA) for high dimensional classification problems. This technique divides each class into a number of subclasses and iteratively estimates the subclass division by embedding the linear discriminant analysis (LDA) with expectation-maximization (EM) in Gaussian mixture models (GMM). The new method maintains the adaptability of SDA to a wide range of data distributions, but provides superior feature selection performance to SDA. It also improves the robustness in problems of small training datasets compared with the conventional EM algorithm. RSDA is successfully applied to the segmentation of prelens tear film into wet and dry regions. Furthermore, a Markov Random Field (MRF) based energy minimization framework is proposed to resolve the sign ambiguity in the phase demodulation of a single closed fringe pattern, which is the most challenging problem in this work. Because the formulated binary pairwise objective function is non-submodular, we devise a multigrid hierarchy of quadratic pseudoboolean optimization scheme to iteratively approximate the global optimal solution. To our knowledge, this is the first path-independent sign ambiguity resolution approach for phase demodulation of single closed fringe patterns, and as such it does not require any heuristic scanning strategy, it is not subject to propagation of the error, and therefore provides superior results to traditional path-following phase demodulation methods. A set of experiments with real tear film narrowband interferometric videos demonstrate the effectiveness and robustness of the proposed tear film thickness analysis system.