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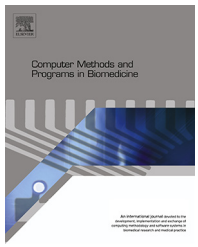

Parallel definition of tear film maps on distributed-memory clusters for the support of dry eye diagnosis

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ABSTRACT

Background and objectives: The analysis of the interference patterns on the tear film lipid layer is a useful clinical test to diagnose dry eye syndrome. This task can be automated with a high degree of accuracy by means of the use of tear film maps. However, the time required by the existing applications to generate them prevents a wider acceptance of this method by medical experts. Multithreading has been previously successfully employed by the authors to accelerate the tear film map definition on multicore single-node machines. In this work, we propose a hybrid message-passing and multithreading parallel approach that further accelerates the generation of tear film maps by exploiting the computational capabilities of distributed-memory systems such as multicore clusters and supercomputers.

Methods: The algorithm for drawing tear film maps is parallelized using Message Passing Interface (MPI) for inter-node communications and the multithreading support available in the C++11 standard for intra-node parallelization. The original algorithm is modified to reduce the communications and increase the scalability.

Results: The hybrid method has been tested on 32 nodes of an Intel cluster (with two 12-core Haswell 2680v3 processors per node) using 50 representative images. Results show that maximum runtime is reduced from almost two minutes using the previous only-multithreaded approach to less than ten seconds using the hybrid method.

Conclusions: The hybrid MPI/multithreaded implementation can be used by medical experts to obtain tear film maps in only a few seconds, which will significantly accelerate and facilitate the diagnosis of the dry eye syndrome.

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1. Introduction

Dry eye syndrome is a chronic, multifactorial disease of the tears and the ocular surface [1], with an increasing prevalence in the last few years, reaching from 10 to 35% of the general population [2]. It has a negative impact on several common tasks of daily living, such as driving or working with computers. For this reason, it is recognized as a growing public health problem which deserves increased attention and resources [3].

The severity of dry eye is correlated to lipid layer thickness [4], and one of the most common diagnostic tests consists in analyzing the interference patterns observed in the tear film lipid layer of the eye. Guillon designed an instrument for rapid assessment of the tear film thickness known as Tearscope Plus [5]. In order to facilitate the use of this instrument, he also defined a grading scale composed of five interference patterns, which in increasing order of thickness are: open meshwork, closed meshwork, wave, amorphous, and color fringe.

This method offers a valuable technique to evaluate the quality and structure of the tear film in a non-invasive way, but it is affected by the subjective interpretation of the observer and by an adequate training [6]. These facts support the use of a systematic, objective computerized system for analysis and classification of interference patterns. For this reason, an automatic version of this clinical test was presented in Ref. [7], which includes the characterization of the interference patterns by means of color and texture properties, and an optimization step to extract them in real-time.

Due to the heterogeneity of the tear film lipid layer, in which multiple patterns may be observed, the classification of a Tearscope image into one single category is not always possible. Therefore, the definition of tear film maps was proposed in Ref. [8] by means of a weighted voting system based on distances and probabilities. An adapted version of the classic seeded region algorithm was subsequently presented in Ref. [9] to improve tear film definition, not only regarding its accuracy (from 80% to 90%), but also in terms of processing time (from more than 60 minutes to less than 10).

However, the time needed to define tear film maps may prevent their clinical use. Parallel computing can be used in order to reduce this runtime and increase their acceptance among medical experts. A multithreaded implementation that provides the same accuracy and further reduces the runtime to around 2 minutes was presented in Ref. [10]. This work is a step forward to further accelerate the tear film map definition using Message Passing Interface (MPI) [11], reducing runtime to only a few seconds.

This paper is organized as follows: Section 2 explains the background necessary to understand the rest of the manuscript, Section 3 presents the parallel approach proposed in this research, Section 4 shows the experimental results and discussion, Section 5 includes the related work and, finally, Section 6 includes the conclusions.

2. Background: tear film mapping

The definition of tear film maps allows to detect multiple patterns per patient, and provides a complete and useful information to support dry eye diagnosis. The algorithm for tear film mapping used in this research was proposed in Ref. [9], and is summarized in Fig. 1.

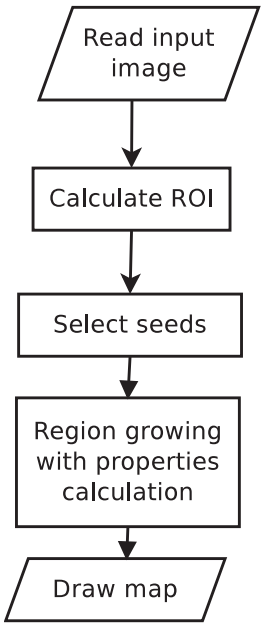

Fig. 1 – Workflow of the sequential algorithm.

Tearscope images include irrelevant parts of the eye such as the pupil or the sclera. Thus, the first step consists in locating the Region of Interest (ROI), in which the tear film map is defined. It is a ring-shaped area automatically located at the most illuminated part of the iris from which the eyelashes, or shadows cast by them, have been removed (see Fig. 2).

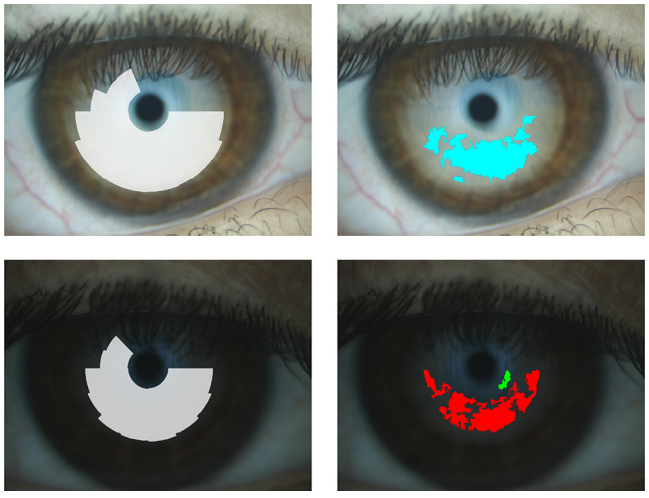

Fig. 2 – From left to right, ROIs and tear film maps represented over two input images.