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Retinal image quality assessment using generic image quality indicators

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ABSTRACT

A retinal image gradability assessment algorithm based on the fusion of generic image quality indicators is introduced. Four features quantifying image colour, focus, contrast and illumination are computed using novel image processing techniques. These quality indicators are also combined and classified to evaluate the image suitability for diagnostic purposes. The algorithm performance is thoroughly appraised through comparison of the automatic classification results of 2032 retinal images from proprietary, DRIVE, Messidor, ROC and STARE datasets with human made classification, revealing a sensitivity of 99.76% and a specificity of 99.49%. The algorithm computational complexity and sensitivity to image noise and resolution were also experimentally quantified demonstrating very good performance and confirming the usability of the solution in an ambulatory application environment.

1. Introduction

Eye diseases such as diabetic retinopathy (DR) and age-related macular degeneration (AMD) affect a considerably large share of the population and its prevalence is expected to increase in the near future [1–4]. Commonly, in order to screen for and diagnose retina related conditions, digital fundus photography is used, which enables a non-invasive examination [5] and allows image storage and transmission for later use at different locations. However, in all cases the resulting digital retinal images must be examined by an expert human grader, usually a trained ophthalmologist or optometrist, which makes the whole process very difficult and time consuming, a problem aggravated by the scarcity of specialised human resources.

Moreover, both DR and AMD are diagnosable, based on well known and perfectly characterised symptoms which are detectable by visual inspection of the eye fundus, and may be treatable if detected at an early stage. These are very strong arguments in support of extensive screening programmes [6]. The use of automated evaluation of digital retinal images has the potential to reduce the workload and thus increase the cost-effectiveness of such screening initiatives, a decisive factor in the implementation of these health surveys. Currently some manufacturers offer automated clinical decision support systems that target these applications [5,6], including Critical Health's Retmarker®, a retinal image analysis tool with diagnostic capabilities. However, there still remain a number of problems that must be overcome in order to develop fully reliable automated retinal images analysis systems. One of these problems is the need to guarantee that the quality of the retinal images to be graded exceeds a threshold below which the automated analysis procedures may fail. This is a real problem as a considerable number of studies [7–13] reported high incidence rates of low-quality images in the range of 4.85–17.3%.

This paper presents a computationally efficient algorithm for automated assessment of retinal image quality, which addresses the concerns just exposed and shows very good performance as reported in the results section.

The paper is structured as follows: in the remaining sub-sections of this section a brief description of the most important retinal image quality indicators is presented followed by a review of recently published work on the subject of image quality assessment; Section 2 consists mostly of a detailed description of the algorithmic solutions proposed and describes the characteristics of the datasets used during the development and testing of the algorithm; Section 3 lists the results of the application of the proposed image quality assessment procedure to the datasets and compares these results to the quality evaluation made by human graders; Section 4 analyses and discusses the results. Finally Section 5 closes the paper by summarising the most important points of the work and drawing some conclusions.

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1.1. Retinal image quality

Retinal image quality may be impaired by a number of factors which can degrade a retinal image to the point of rendering it "ungradable", which by definition is a retinal image with insufficient quality and without signs of disease. According to the study "Atherosclerotic Risk in Communities (ARIC)" performed by the University of Wisconsin-Madison [14] the parameters focus and clarity, field definition, visibility of the macula, visibility of the optic disc, and artefacts are very important for the correct evaluation of retinal image quality. The study found that the image artefacts are mostly caused by the occurrence of haze, presence of dust and dirt, partial occlusion by eyelashes, improper cleaning of the camera lens, uneven illumination over macula, uneven illumination of the optic disc, uneven illumination of the image edge, and total eye blink. Fig. 1 shows some examples of impaired retinal images which illustrate clearly the severe effect of these artefacts on the visibility of the retina.

The parameters identified by the ARIC study as being the most important ones can be divided into two major categories: generic image quality parameters such as focus and clarity, absence of artefacts caused by haze, dust and dirt, eyelashes, improper cleaning of the camera lens and total eye blink and structural quality parameters such as field definition, visibility of the optic disc, and visibility of the macula.

As will be described shortly, our work evaluates retinal image quality through classification of features derived from generic image quality parameters.

1.2. Previous work on retinal image quality assessment

In the context of DR, AMD and other eye-related diseases diagnosis, retinal image quality assessment is used to grade an image according to its usefulness to the patient's eye health evaluation. Additionally this quality grade provides an indication of the reliability of the patient's health appraisal based on retinal image examination. Logically it is very important to include provisions for image quality assessment in the development of complete and trustworthy software for automated analysis of retinal images.

Image quality classifiers based on generic image quality parameters make use of simple image measurements to estimate image quality avoiding eye structure segmentation procedures which usually are complex and time consuming tasks. Several proposals for image evaluation procedures fulfilling these requirements have been published. In 1999, Lee and Wang [15] proposed a method based on a measure of the similarity between a template histogram and the histogram of the retinal image to be classified. In 2001, Lalonde et al. [16] proposed a method to evaluate image focus and illumination based on the analysis of the global distribution of edge magnitudes in the image and on local analysis of intensity distribution. In 2009, Bartling et al. [17] focused their quality assessment algorithm on image sharpness and illumination. Illumination quality was measured through evaluation of retinal image contrast and brightness. The image was partitioned into non-overlapping square regions which were analysed separately with the regions quality indicators pooled to form the overall quality indicator. The computed quality indicators were evaluated on a set of 1000 images and were found to agree with the quality scores attributed by human graders, with kappa values [18] ranging from 0.52 to 0.68 with a median value of 0.64. Also in 2009 Davis et al. [19] described a retinal image quality assessment procedure which relies on 17 simple features calculated for each colour channel in the CIELab space [20]. Making use of those features the authors evaluated the image along the dimensions of colour, luminance and contrast, achieving an overall sensitivity of 100% and a specificity of 96% in identifying ungradable images in five small 200 image datasets.

The greatest advantage of the image quality assessment methods based on generic image quality is their algorithmic simplicity which translates into reduced computational complexity making

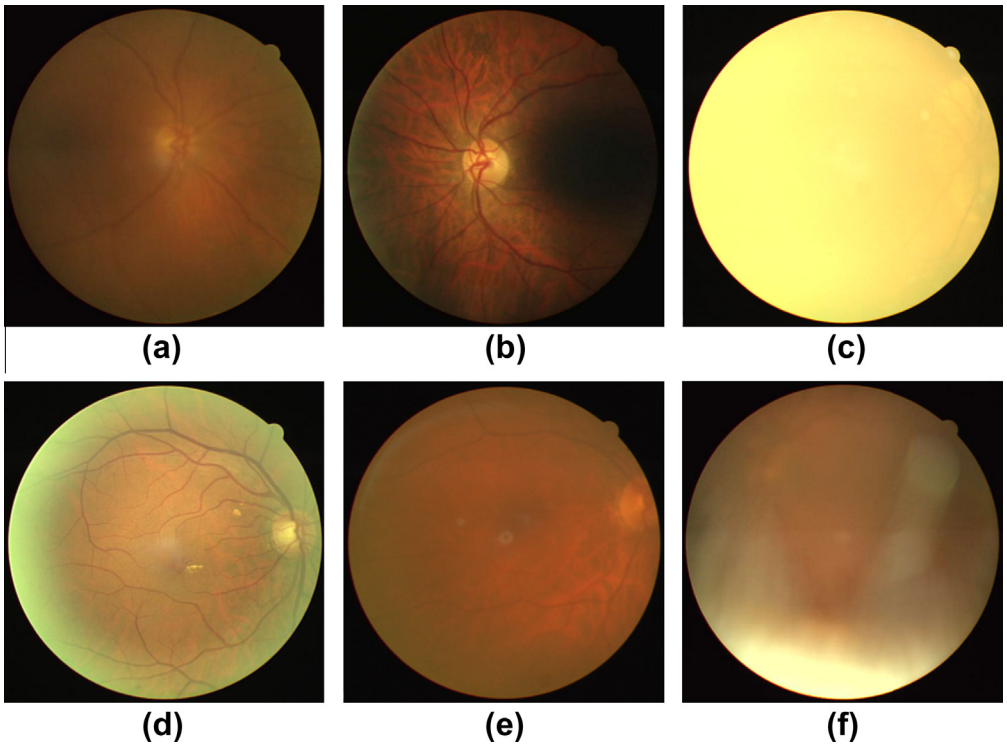

Fig. 1. Examples of impaired/ungradable images. (a) Poor focus and clarity due to overall haze. (b) Poor macula visibility due to uneven illumination over it. (c) Poor optic disc visibility due to total blink. (d) Edge haze. (e) Dust and dirt artefacts (near the centre). (f) Lash artefact.