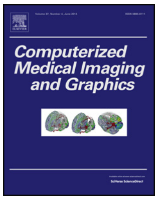
Computerized Medical Imaging and Graphics 37 (2013) 369–376

Contents lists available at ScienceDirect

Computerized Medical Imaging and Graphics

journal homepage: www.elsevier.com/locate/compmedimag



The use of radial symmetry to localize retinal landmarks

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ARTICLE INFO

Article history:
Received 5 December 2012
Received in revised form 19 June 2013
Accepted 20 June 2013

Keywords:
Optic disc
Fovea
Fast Radial Symmetry

ABSTRACT

Locating the optic disc center and the fovea in digital fundus images is surprisingly difficult due to the variation range in color and contrast and the possible presence of pathologies creating bright spots or changing the appearance of retinal landmarks. These reasons make it difficult to find good templates of optic disc and fovea shape and color for pattern matching.

In this paper we propose radial symmetry as the principal cue to locate both optic disc and macula centers. Centers of bright and dark circularly symmetrical regions with arbitrary radii, can be found robustly against changes in brightness and contrast by using the Fast Radial Symmetry transform. Detectors based on this transform coupled with a weak hypothesis on vessel density (optic disc intersects large vessels while the fovea lies in an avascular region), can provide a fast location of both OD and macula with accuracy similar or better than state-of-the-art methods. The approach has been chosen as the default technique for fast localization of the two landmarks in the VAMPIRE software suite.

1. Introduction

One of the most important tasks in retinal image processing is the location of the optic disc (OD) and of the macula, or, better, its central part, the fovea. The location of such landmarks is a prerequisite for the algorithms detecting signs of several retinal diseases. OD and fovea are often identified in digital fundus images with heuristics based on color and shape priors. The significant variability of their appearance, however, makes it difficult to devise template based detectors working well on poor- or limited-quality images and in the presence of anomalies. Solutions proposed in the literature use heavily contextual information (e.g. vascularization). This makes the detector more robust, but can make the localization less accurate. Furthermore, anomalous cases may create problems in training multivariate models of objects and context. A possible alternative to a rigid modelling of the context is to find detectors that capture the peculiarities of the target landmarks better and are less sensitive to noise and disturbances, adding only a “soft” contextual reasoning to cope with anomalous cases.

In this paper we show that radial symmetry is a simple and effective cue to detect OD and fovea, and locate their centers. While it is difficult to find a good template for the fovea, and while different templates proposed so far for the quick detection of the OD do not outperform a simple bright circle, as shown by Yu et al. [1], we found that the use of a radial symmetry detector can considerably improve robustness and accuracy with respect to other methods. Both optic OD and fovea have variable appearances (shape, contrast with background, color components), but the OD, after vessel removal, is almost always characterized as a radially symmetrical bright spot, and the foveal region is better characterized as a radially symmetric dark region than as the darker part of the image, or a part with a specific shape (e.g. a circle of specific radius). Furthermore, the OD should always be crossed by the largest vessels, while the center of the foveal region is avascular.

We use the Fast Radial Symmetry (henceforth FRS) transform [2] to detect and localize centers of symmetry of dark and bright regions of arbitrary radius, independent of the presence of evident contrast or edges. This allows us to design specific OD and fovea detectors, computing this transform on vessel-inpainted and coarsened images and combining the results with a vascular density estimator.

This work has been carried on within the VAMPIRE project [3]. VAMPIRE (Vessel Assessment and Measurement Platform for Images of the REtina) is an international collaboration of 10 image processing and clinical centers, developing a software suite allowing efficient semi-automatic measurements on the retinal vasculature.

2. Related work

OD and macula detection in digital fundus images is deceptively simple: images quality can vary heavily in clinical samples of even modest size, lesions may create false targets, and even a normal OD is covered by vessels of irregular and variable shape.

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http://dx.doi.org/10.1016/j.compmedimag.2013.06.005

Approximate automatic detection of the OD center has been achieved using simple features (e.g. brightness, edges) and template matching, using ad hoc heuristics to avoid false detections [4–6]. The result is used directly to estimate parameters and regions of interest, or to initialize accurate contour segmentation methods [7,8,1]. Simpler methods can fail in noisy cases; to overcome this problem, "robust" OD location techniques using contextual information, mainly related to the geometry of the vascular tree, have been proposed by several authors using local maps [9,10] or vascular models [11–13]. Context can be advantageous when the OD is nearly invisible, but results depend on the quality of the vascular segmentation. Furthermore such techniques do not sometimes provide good feature localization. Recent works reporting good OD localization and validated on large image sets [8,1] use multiple cues based on local brightness to find the OD center, even based on 1D projections [14] rather than training complex models.

In any case, finding good features to characterize the OD independent of image quality or lesions is still an open issue. Yu et al. [1] showed recently that complex OD templates proposed in literature do not improve localization performance with respect to convolution with a simple binary circular template.

Fovea localization based on local image properties is even more difficult. Methods reported in the literature exploit more heavily vasculature and other contextual information. Sinthanayothin et al. [4] used correlation with a template to locate candidate regions, selecting the darkest one. Chutatape [15] segmented the main blood vessels with an active shape model, then fitted a parabola to the result to indirectly locate the fovea. Welfer et al. [16] exploited OD location to constrain a candidate region where the fovea was identified with morphological processing. A similar approach was used by Yu et al. [17], finding the fovea as the point of lowest matched filter response within a search area determined by the optic disc location. Chin et al [18] used geometrical priors coupled to vascular density. Niemeijer et al. used a combination of global and local cues [19] and in [13] defined the problem of localizing retinal structures as a regression problem on a large feature space. The usual risk in learning based or regression methods combining different parameters is the inability to provide reasonable results when the training set does not cover the characteristics of images to be analyzed. This is a general problem in medical decisions, as it is often not obvious whether the use of complex models involving several parameters and trained classifiers is better than the use of simple heuristics [20].

The substantial amount of techniques and heuristics reported, of which the cited papers are but a representative sample, suggests that it is still necessary to investigate improved retinal features detectors possibly not influenced by color and quality variability of fundus images.

In this work we show that very good results for both OD and fovea location can be obtained even on difficult images by making limited and general assumptions on bright or dark radial symmetry of the searched landmarks and on local vessel density, without training complex models on specific data, and without contour detection.

3. The proposed approach

The algorithm is based on the computation of likelihood values for pixels to be OD or fovea centers, derived from the FRS transform and vessel density estimation. We start by rescaling images to obtain a reference pixel size (reference image). A rough (morphology-based) vessel removal and an accurate inpainting procedure [21] are then performed to obtain a image with vessels and other small dark spots removed that is used for the symmetry detection. This image is furtherly subsampled at the resolution chosen for the symmetry analysis that corresponds, for the images tested in the experimental section to a 200 pixel width and to an expected OD size of about 10 pixels and pixel size of about 0.05 mm (coarse image). This low resolution is sufficient to obtain the good results described in the experimental section keeping the computation time small.

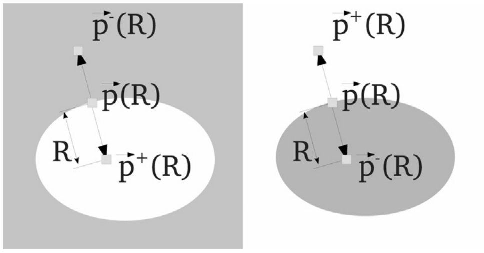

Fig. 1. Fast Radial Symmetry: each pixel generates a positively affected pixel $\vec{p}_+$ at distance R along the positive gradient direction, and a negatively affected pixel $\vec{p}_-$. Summing contributions in the "affected pixels" generated by all the image pixels we obtain functions that are maximal near centers of bright or dark circular shapes with radius R.

3.1. Fast Radial Symmetry transform

The Fast Radial Symmetry (FRS) transform is created with a voting procedure fully described in [2] and that can be summarized in our customized version as follows. For each radius R in a defined range and for each pixel location $\vec{p}$, a positively affected pixel $\vec{p}_+$ and a negatively affected pixel $\vec{p}_-$ are obtained translating $\vec{p}$ along the gradient direction in positive (dark to bright) and negative (bright to dark) orientations (see Fig. 1):

$$\vec{p}_+(R) = \vec{p} + round\left(\frac{\nabla I(\vec{p})}{||\nabla I(\vec{p})||}R\right) \tag{1}$$

$$\vec{p}_-(R) = \vec{p} - round\left(\frac{\nabla I(\vec{p})}{||\nabla I(\vec{p})||}R\right), \tag{2}$$

where *round* indicates closest integer.

Summing values in these points we build two maps enhancing centers of bright and dark circularly symmetrical regions. Differently from [2], in fact, we create separate maps for the positive and negative contributions and use them to detect OD and fovea.

To create the first one we scan image pixels and for each pixel position $\vec{p}$, we consider only the positively affected pixels $\vec{p}_+$. Incrementing a counter in all that locations we first obtain a map called "orientation projection image" O_R^+. Summing in that positions the gradient modules computed in the originating pixels, $||\nabla I(\vec{p})||$ we obtain the so-called "magnitude projection image" M_R^+. Finally, the *bright radial symmetry response map* S_R^+ is defined as

$$S_R^+ = F_R^+ \cdot A_R, \tag{3}$$

where

$$F_R^+(\vec{p}) = \frac{M_R^+(\vec{p})}{k_R}\left(\frac{\max(O_R^+, k_R)}{k_R}\right)^\alpha \tag{4}$$

In the above, A_R is a radius-dependent Gaussian kernel, that is in our case taken with $\sigma = R/4$, α is the "radial strictness parameter" (higher values create more peaked maps) that we take equal to 2. The clamping parameter k_R is taken equal to 9.9 if $R > 1$ and 8 if $R = 1$ as suggested in [2]. To detect symmetries at varying radii, Loy and Zelinsky [2] summed contributions at various values of R, showing that if radii are sampled densely enough (every 2 pixels according to [1]) in a given range, all the symmetric structures within that range are captured. This means that a detector for an approximately symmetric structure like the OD can be built computing S_R^+ in a