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Original paper

Automated segmentation of ophthalmological images by an optical based approach for early detection of eye tumor growing

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ABSTRACT

Purpose: Iris neoplasm is a non-symptom cancer that causes a gradual loss of sight. The first purpose of this study was to present a novel and automatic method for segmenting the iris tumors and detecting the corresponding areas changing along time. The second aim of this work was to investigate several recently published methods after being applied for the iris tumors segmentation.

Methods: Our approach consists firstly in segmenting the iris region by using the Vander Lugt correlator based active contour method. Secondly, by treating only the iris region, a K-means clustering model was used to assign the tumorous tissue to one pixel-cluster. This model is quite sensitive to the center initialization and to the choice of the distance measure. To solve these problems, a proportional probability based approach was introduced for the cluster center initialization, and the impact of several distance measure was investigated. The proposed method and the different comparative methods were evaluated on two databases: the Eye Cancer and the Miles Research.

Results: Results reported using several performance metrics reveal that the first step assures the detection of all iris tumors with an accuracy of 100%. Additionally, the proposed method yields better performance compared to the recently published methods.

1. Introduction

Human iris assumes a significant part in the visual system by controlling the light achieving the retina. However, tumors can grow inside the iris and cause by that a gradual loss of sight. The iris tumors start when one of the nevi (pigmented spot) changes, enlarges, or pulling on the pupil. Further, it is known that the Glaucoma, a disease that damages the eye's optic nerve, is one of the major reasons of sight loss [1]. Nearby the Glaucoma, pupil deformation, development of a cataract beneath the tumor, and blood vessels within the tumor are the characteristics suggesting that the iris tumors are cancerous. Besides, the most dangerous feature of the iris tumors are usually a non-symptom tumors which can only be noticed by an eye-care specialist during examination. For that, large biomedical machines are used in order to diagnose the iris cancer. Meanwhile, medical image processing methods have shown to be important techniques for detecting the tumorous tissue and also, providing information for shape analysis, detecting volume changes, and making a precise treatment plan. Further, image processing and especially image-segmentation methods [2] are popular approaches that have provided solutions to the medical problematic in relation to the brain [3–5], liver [6], gross tumor volume [7], CT dose optimization [8], and image-guided radiotherapy [9]. With this in mind, medical image processing of the iris tumors can also be useful for the development of patient specific solutions.

Despite the growing number of works investigating several ophthalmology problems, to the best of our knowledge, there has yet to be any automatic system that detects the iris tumors and the corresponding areas changing along the time. Nevertheless, several research efforts have been carried out for other properties in relation to the human eye (temperature, fluid dynamics, stress …). For instance, a 3D boundary element model of the human eye was developed by Ooi et al. to simulate the thermal effects of the eye tumor where the steady state temperature inside the tumor is governed by the Pennes bioheat equation [10]. Further, authors in [11] provide a 3D computational fluid dynamics model of the eye based on the anatomy of a real human eye in order to serve future evaluation of new Glaucoma surgical techniques. In addition, for making clinical MRI systems more reliable in eye imaging, Tsiapa et al. selected MRI pulse sequences and evaluated their utility for depicting specific anatomic regions in the eye. As a result, authors developed a comprehensive MR eye imaging protocol with a High-Resolution (HR) of $0.08 \times 0.08 \times 0.60\ mm^3$, better spatial resolution, and higher Signal-to-Noise Ratios (SNR) [12]. As matter of

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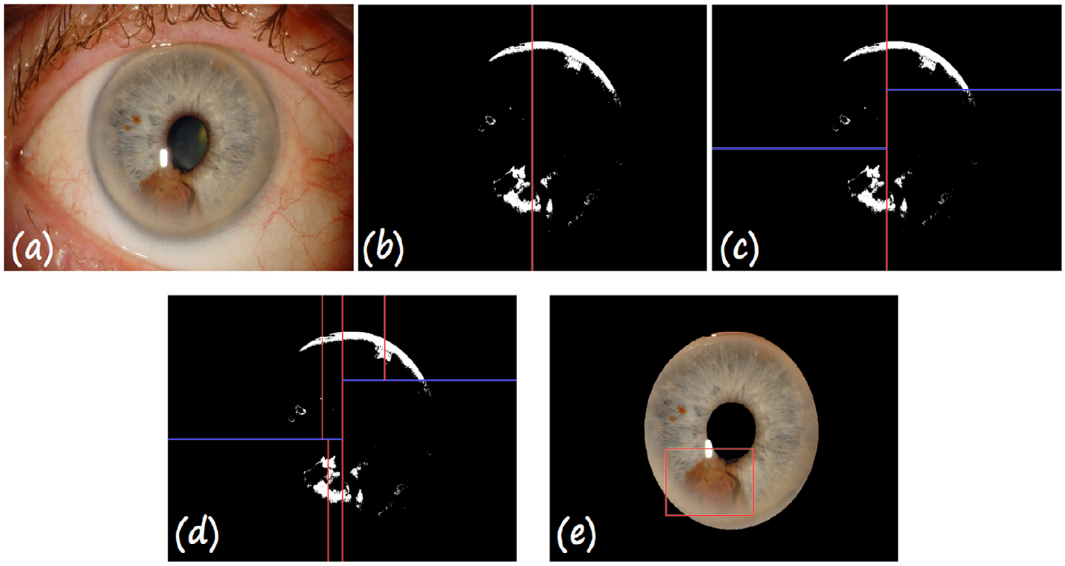

Fig. 1. Iris tumor detection by HCSD method after image binarization and image decomposition via the kd-tree structure. (e) shows the bounding box where the iris tumor is enclosed.

fact, there are few works focusing on image-processing techniques for the segmentation of iris tumors. Author in [13] proposed a seven-step system for the iris tumors segmentation based on images filtering, background adding, and tumors segmenting using the Canny operator. The drawback of this algorithm is that the method could not segment only the tumors. Because of the overall treatment of eye images, regions (as pupil region) are detected as tumorous tissue. Furthermore, because eye disease is the leading cause of blindness and consequently, an early detection is important, Sharp developed a software to assess the quality of retinal images and, if quality was sufficient, to identify the presence of eye disease, namely microaneurysms, exudates and haemorrhages. As a result, the software was shown to provide a cost-effective way of reducing the number of retinal images needing examination by an ophthalmologist [14]. On the whole, the use of the recent image processing methods is not present in the iris tumors segmentation literature.

Popular methods in the image segmentation literature, used for tumorous tissue segmentation, are only applied on brain tumor segmentation. Unfortunately, applications of these methods for the iris tumors segmentation are not presented in the image processing literature. With this in mind, we propose in the current work a two-stage system for the iris tumors segmentation first, followed by an investigation of some popular methods after being applied for the iris tumors segmentation. In the first stage of the proposed system, a numerical simulation of the optical Vander Lugt correlator is used with an active contour model for iris region segmentation. The aim of this first stage is to isolate the iris region where iris tumors grow and maximizing by that the accuracy of the proposed system in terms of the iris tumors detection. The good performance of this method is already demonstrated in our previous work on iris segmentation for personal identification [15]. The second phase consists of using a K-means clustering model in order to extract the tumorous tissue presented with a specific cluster. Equally important, we investigate the impact of several objective functions on the algorithm performance. As a result, we find out the distance measure that provides perfectly the desired pixel distribution of iris tumors. Our main contributions are highlighted as follows:

(i) We propose to use a numerical simulation of the optical Vander Lugt correlator and an active contour method for iris region segmentation in images from the Eye Cancer [16] and the Miles Research [17] databases. The use of this first stage maximizes the proposed system accuracy in terms of the iris tumors detection.
(ii) We employ several kinds of distance measure in the objective function of the K-means algorithm in order to segment regions of the iris tumors presented with a specific cluster.
(iii) We propose to apply some of the recently published methods for the iris tumors segmentation in order to highlight the advantages of the proposed method and present an aggregate overview of the several techniques results.

2. Foundations

In this section, we describe some of the recently published methods in the image processing, such as: Hierarchical Centroid Shape Descriptor (HCSD) based localized active contours, Potential Field Segmentation (PFS), Vander Lugt Correlator based Active Contour (VCAC), and K-means clustering algorithms (K-means). At the same time, we investigate some of these methods after being applied for the iris tumors segmentation.

2.1. HCSD based localized active contour

Proposed in [5] for brain tumor detection, the Hierarchical Centroid Shape Descriptor (HCSD) is a shape descriptor for detecting tumorous tissue in binary images based on centroid coordinates. This five-step algorithm is based on the decomposition of the spatial pixels distribution by using the k-dimensional tree (kd-tree) algorithm. Firstly, the image must be transformed to a binary image to compute its transposed I^T. Secondly, centroids at the root level $C(x_c,y_c)$are computed using the equation:

$$x_c = \frac{m_{10}}{m_{00}}, y_c = \frac{m_{01}}{m_{00}} \quad (1)$$

where m_{10} is the first order moment along the x axis, m_{01} is the first order moment along the y axis, and m_{00} is the area of the binary image with foreground I_f. The raw moments m_{pq} of a digital image with pixel intensities $I(i,j)$, are calculated by:

$$m_{pq} = \sum_{i=0}^{M} \sum_{j=0}^{N} i^p j^q I(i,j) \quad (2)$$

Thirdly, by using the lines $x = x_c$ or $y = y_c$, the image is divided recursively in two sub-images until the desired depth of decomposition is reached. After that, the obtained vector is normalized in the range of $[-0.5,0.5]$ where the point 0 corresponds to the centroid of the root