Iris segmentation using a non-decimated wavelet transform

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Abstract

This paper presents an iris segmentation algorithm. The proposed technique applies a histogram based method on the input eye image extracting a point within the pupil. The image is then intensity sampled over M equiangular radial scan line, generating M 1-dimensional signals. A Fuzzy multi-scale edge detection algorithm is then applied to each of the resulting radii signals, to accurately detect and locate one positive edge point from the signal. A uniform cubic B-spline approximation method is further applied to the detected edges determining the iris outer boundary. The histogram of the area within the extracted outer iris bondary of the eye image is finaly used to extract the pupil outer bondary. Experimental results on a number of eye test images taken under visible wavelenght from UBIRISv.1 and UBIRISv.2 databases show that the proposed segmentation method accurately extracts the iris boundaries.

1 Introduction

Iris segmentation plays a key role in success of any iris recognition system. Iris images captured under visible wavelengths significantly suffer from heterogeneous qualities and multiple noise factors. This increases the probability of mis-segmenting the sclera portion around the outer ring of the iris; this could undermine the performance of the iris recognition systems [1]. Iris segmentation algorithms can be classified into three main groups: iris extraction based on extractiong iris outer and inner boundar methods [2], iris template matching techniques [3,4,5] and the hybrid schemes [6].

Daugman proposed the first successfully implemented iris segmentation method in [3]. It assumes that iris and pupil are in circular shape and applies an integro-differential operator to the eye image to determine the pupil centre and radius for both inner and outer iris circle. The integro-differential operator fails when the intensity changes between the coloured region of the iris ring and the white region of the sclera. However, it was shown in [1] that Daugman integro-differential operator can segment iris images with good quality but it fails when segmenting noisy images like those presented in UBIRIS.v1 and UBIRIS.v2 databases [7]. Camus and Wildes in [4] proposed an algorithm for extracting iris inner and outer boundary extraction based on the maximum summation of directional derivative of image intensity in radial direction. Their proposed method operates in a very similar fashion to Daugman's method that determines the centre point and the radius of iris pupil circular shape. Camus and Wildes' method produces superior and faster results than Daugman's method. In addition it can process images with specular reflection. However, the results are still unacceptable under other noise factors. A boundary based iris segmentation method was proposed by Wildes in [2]. The proposed method performs iris segmentations using circular contours fitting in two steps: It first generate the edge map of the eye image using Canny edge detection method; It then uses the circular Hough transform to determine radius and centre coordinate values for a particular contour. The proposed method works well when it applied to an image with higher SNR. However the method is sensitive to noise due to use particularly when the level of noise is unknown. Proença and Alexandre proposed an iris segmentation method based on moments function [7] and clustering followed by canny edge detection and circular Hough transform in [8].

The Proença and Alexandre's method is first perform a feature extraction on the eye image using the texture segmentation algorithm proposed by Tuceryan in [7]. They then employed a Fuzzy K-Mean clustering algorithm to discrimination between the pixels that belong to iris region and the pixels that belong to the remaining eye regions. After the clustering step, a Canny edge detector will be applied to the resulting image generating an image which is less to less sensitive to the noise introduced by light reflection and obstruction of the eyelids and eyelashes. Finally the circular Hough transform is applied to the edge map to approximate the inner and outer iris rings. The proposed technique exhibited more robust to noise to the state of the art techniques. An iris segmentation method, which claims to be more robust to noise, was introduced in [9]. The proposed method first searches for sclera region over Hue, chromatic blue and chromatic red spaces, to roughly detect the pixels with high intensity values representing the sclera area to extract the eye. It then applies a feature extraction algorithm to each pixel of the image. The extracted features are then used to classify the pixels into iris or non-iris groups using a combinational of neural network and support vector machine. The Authors reported improvement on iris classification from noisy eye images in compared to the state of the art techniques. As it can be seen various attempts in iris classification from noisy images have been done over the past years. However, the application of multi-scale edge detection techniques for segmenting iris images when level of noise is unknown has not been reported in the literature.

In this paper, a robust iris segmentation method is presented. The proposed method uses a novel Fuzzy multi-scale edge detection algorithm followed by a uniform cubic B-spline approximation method to robustly extract the iris outer boundary. The iris inner boundary is defined using a histogram based algorithem. Results shows the the proposed algoritm more acuratly segments the iris images. The rest of the paper is organized as follows: in Section two the proposed iris segmentation method is explained. In section 3 experimental results are given and finally the paper will be concluded at section 4.

2 Fuzzy and wavelet based iris segmentation technique

The proposed iris segmentation algorithm extracts iris boundries in thee steps: it first determines a point within the pupil area using a histogram method; it then applyes a Fuzzy Multi-Scale Edge Detection (FMSED) algorithm to extract iris outer boundry and finally it uses a histogram algorithm to extract the iris inner boundary from the eye image. To locate a point within the pupil area, the proposed technique first determined the histogram of the eye image in grey colour domain. The resulting histogram is then recursively filtered using an FIR lowpass Gaussian filter (the filter coefficients are: 0.25, 0.50 and 0.25) until it end up with two distinct peaks. The first minimum value of the histogram is chosen as a threshold and used to convert the grey eye image to a binary image where pixel with values grater than the thresholds are set to zeros. The resulting binary image is then processed using morpholegical operators, e.g. imdilate, imerode and imfill, generating blobs, where the blob with the biggest are represents an area withn the puple. The centre of this blob is selected as the reference point for generating the radii vectors, which are used to extract iris boundary. This is similiar to the way that most of the iris recognation systems search for iris area.
In NIR iris images the transition intensity from the pupil area to iris is more significant than the transition from iris area to the limbus area while in visible wavelength iris images the transition from iris area to the limbus area is more significant, as shown in Figure 1.

Since this paper deals with iris images taken under visible wavelenght, the second stage of the algorithm is to serach the outer boundary of the iris. To do that, the eye image is intensity sampled over M equiangular radial scan line. A Fuzzy Multi-Scale Edge Detection (FMSED) algorithm is then applied to each of the resulting radii image intensity

(a) (b)

Figure 1. Iris image taken under a) NIR [10] and b) visible wavelength.

profile, to accurately detect and locate one positive edge point from the radii image profile. This point represents one point on the outer iris boundary. The extracted edge points from the radii image intensity profiles are then used to define limbus boundary. The implementation of the FMSED is as follows:
The FMSED first computes the non-decimated discrete dyadic wavelet transform of the 1D radii image intensity profile in all its available scales j $(j = 1,2,\ldots,J)$ using non-orthogonal wavelet and the fast computation algorithm introduced by Mallat et al in [11]; Since transition from iris area to limbus area represents a positive edge and positive components of the wavelet subbands carry this information, the FMSED replaces all the negative components with zeros:

$$f\ (j,n) = \begin{cases} 0 & \text{if } f(j,n) < 0 \\ f(j,n), & \text{if } f(j,n) \geq 0 \end{cases} \quad \text{for any } \substack{n=1,2,\ldots,N \\ j=1,2,\ldots,J} \qquad (1)$$

As the range of the membership function of a fuzzy subset is a real interval $[0\,,1]$, the FMSED normalises the coefficients in each scale of $f(j,n)$, in order to have a maximum value equal to one and produces $S_j^1(n)$:

$$S_j^1(n) = F_1[f\ (j,n)] \qquad (2)$$

The normalization operator $F_1[.]$ is defined as: $hgt(S_j^1) = 1$ for all $j = 1,2,\ldots,J$ where $hgt(.)$ is the height operator, which represents the maximum value of the input function [12]; Since in the finer scales, signal is more dominated by noise than in the coarser scales, the FMSED weights and offsets the scales to reduce the effect of lower scales in finding the location of the edge:

$$\begin{aligned} S_j^2(n) &= F_2[S_j^1(n)] \\ &= \left(\frac{1}{a^{(J-j+1)}}\right) S_j^1(n) + \left(1 - \frac{1}{a^{(J-j+1)}}\right) \qquad (3) \\ &\quad \text{for any } \substack{n=1,2,\ldots,N \\ j=1,2,\ldots,J} \end{aligned}$$

The value of α is chosen empirically. It can take any value greater than one. Increasing its value increases the effect of higher scales in finding the location of the edge. In this experiment α =1.3 found to give the most accurate results; As local maxima in the resulting scales are representative of positive transitions in the signal, which could be the real edge, FMSED assigns a membership of one to these local maxima; Operator $F_3[.]$ assigns one to local maxima in all the scales:

$$S_j^2(n) = F_3[S_j^1(n)] = \begin{cases} 1 & \text{if } S_j^1(n) \text{ is a local maximum;} \\ S_j^1(n) & \text{else;} \end{cases} \quad \text{for any } \begin{matrix} n=1,2,\ldots,N \\ j=1,2,\ldots,J \end{matrix} \tag{3}$$

Normalization and assigning ones to the local maxima produce a fuzzy membership function for all the scales. The membership function for each scale can be defined as:

$$A_j = \left\{ \left(n, \mu_{A_j}(n) \right), \quad n = 1,2,\ldots,N \right\}, \quad j = 1,2,\ldots,J \tag{4}$$

where $\mu_{A_j}(n)$ is the grade of membership for the point '*n*' in the fuzzy subset A_j with magnitude $\left| S_j^2(n) \right|$; The final step in the creation of the FMSED is to combine the information contained in the different fuzzy subsets of the 1D radii image intensity profile. The FMSED discards the information provided by the finest scale as the information there, is dominated with high levels of noise; It then determines the fuzzy intersection among the rest of the fuzzy sets. That is:

$$A_E = A_2 \cap A_3 \cap \ldots \cap A_k \tag{5}$$

where A_E is the edge fuzzy set of the signal with the membership function:

$$\mu_{A_E}(n) = \min_{1 < j < k}(\mu_{A_j}(n)), \quad n = 1,2,\ldots,N \tag{6}$$

Finally, a uniform cubic B-spline approximation method is applied to the detected edges from the 1-dimentional M radii eye image signals, defining the iris outer boundary.

The larger the membership value $\mu_{A_E}(n)$ for the point '*n*', the more probable the point 'n' is the edge. The pixel with the maximum membership value shows the place of the edge in the signal:

$$\mu_{A_E}(n_0) = \max_{1 \le n \le N} \left(\mu_{A_E}(n) \right) \tag{7}$$

Finally, a uniform cubic B-spline approximation method is applied to the detected edges from the 1-dimentional M radii eye image signals, defining the iris outer boundary.

To determine pupillary boundaries of human iris images, the proposed iris segmentation algorithm first applies a histogram algorithm on the area within the iris outer boundary of the eye image (grey eye image). The resulting histogram then recursivley filtered using the FIR lowpass Gaussian filter, which was introdued earlier until it end up with a global minimum. This global minimum value is the chosen as a threshold and is used to generate a binary map for the pupile. Morphological operators are then used to extract the pupile area. The iris iner boundary is determined using a simple edge detection algorithm.

3 Experimental results

In order to demonstrate the application of the Fuzzy Multi-Scale Edge Detection (FMSED) technique in detecting and locating an edge from a 1-dimentional radii image intensity signal, the radii signals are simulated with a noisy signal of length 128 with two main edges located at samples 32 and 64 and the signal is corrupted with Gaussian noise with zero mean and standard deviation 0.6 as shown in Figure 2a, where the edge at sample 64 is the highest, representing a point on the boundary of the limbus, and the edge at sample 32 represents a point on inner iris boundary. The FMSED is then applied to this signal extractin the location of the highest edge. A set of six fuzzified scales produced by the FMSED technique is illustrated in figures 2c-2h. Figure 2i illustrates the combined scales information using the fuzzy intersection operator of the FMSED. The maximum of this combined scales function is chosen as the detected edge and marked with a cross on Figure 1b, which shows the noise free signal.

In order to perform a quantitative evaluation of the proposed FMSED algorithm, it was applied to a test data set of the radii like 1-dimensional signal introduced above. In the first set of experiments a Gaussian zero mean noise with increasing standard deviation from 0.2 to 0.6 in the steps of 0.2 is added to the signal. Table 1 shows the RMSE (from the actual edge location) performance figures for the methods. These figures are the ensemble average of 10,000 runs with α = 1.3.

Sigma	RMSE
0.2	0.82
0.4	1.28
0.6	2.31

Table 1 RMSE results for FMSED method for extracting a single edge at different Gaussian noise.

An example of different steps of the application of the proposed iris segmentation algorithm for extracting iris outer and iner boundaries from an eye image taken under visible wavelenght is shown in Figure 3. Figures 3a-c illustrate: the extracted centre of pupile and the 1-dimentional radii image intencity signals, detected edges from each radii signals, and

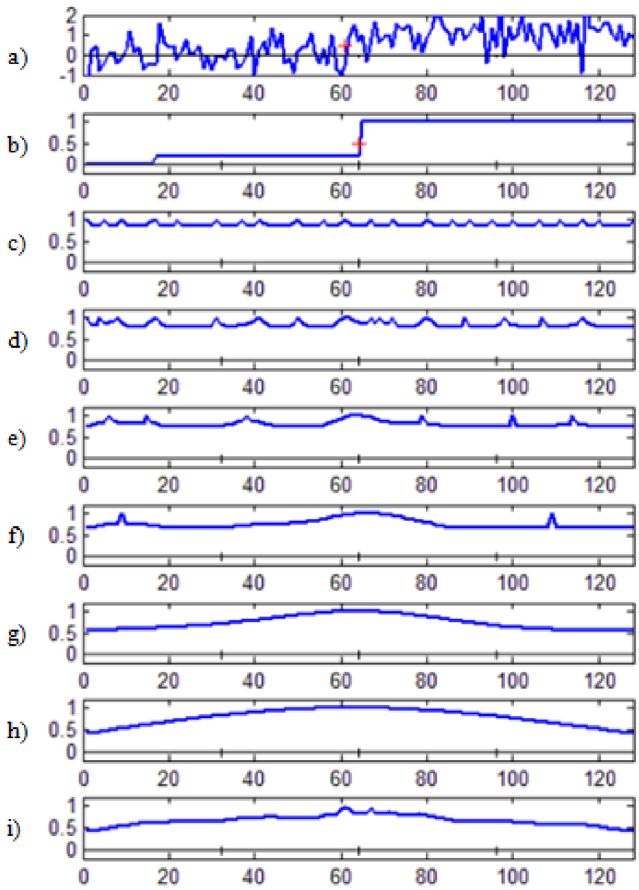

Figure 2. Application of the FMSED on a simulated 1D radii image intensity signal.

extracted iris-outer boundary respectively. Figure 3d finally shows both extracted iris inner and outer bounday overlayed on the eye image. From this figure, it is clear that the proposed technique has accuratly segmentd the iris image.

4 Conclusions

In this paper, a robust iris boundary extraction algorithm from eye images captured under visible wavelength was presented. The proposed method first uses a histogram based algorithm to locate a point within the pupil. It then selects a number of 1-dimensional radii image signals beginning from the chosen point within the pupil area. A Fuzzy non-decimated wavelet based edge detection algorithm was then employed to identify a positive edge on each radii signal, representing a point on the iris outer boundary. The detected edges were then converted to the iris outer boundary using a uniform cubic B-spline approximation method. A smoothed histogram of the area within the outer iris boundary of the eye image was used to generate a binary image representing the pupil area. The resulting binary image was then processed using morphological operations followed by edge detection to extract iris inner boundary. Experimental results on a number of standard test images show that the proposed method accuratlty segments the iris images.

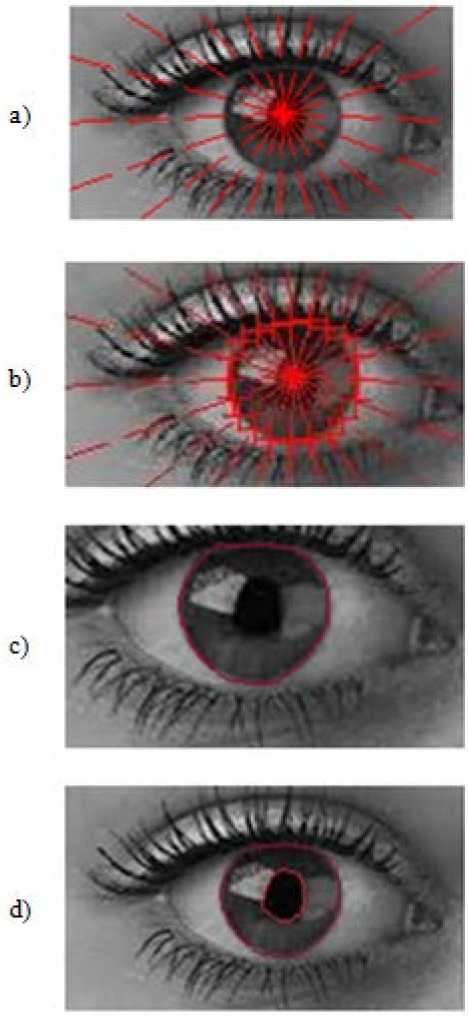

Figure 3. Application of the proposed iris segmentation method in extracting iris boundary: a) selection of the radii signals, b) extracted edges from the radii signals, c) extracted iris outer boundary overlaid on the eye image and d) segmented iris (Image courtesy of CASIA [10]).

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