H. Mehrabian, P. Hashemi-Tari, 'Pupil Boundary Detection for Iris Recognition Using Graph Cuts', *Proceedings of Image and Vision Computing New Zealand 2007*, pp. 77–82, Hamilton, New Zealand, December 2007.

Pupil Boundary Detection for Iris Recognition Using Graph Cuts

H. Mehrabian[1], P. Hashemi-Tari[2]

[1]Dept. Electrical and Computer Engineering, University of Western Ontario, London Ontario, Canada
[2]Dept. Civil and Environmental Engineering, University of Western Ontario, London Ontario, Canada

Email: hmehrabi@uwo.ca, phashemi@uwo.ca

Abstract

In this paper an automatic segmentation method for accurate pupil boundary detection for iris recognition purpose using graph cuts is presented. Most iris segmentation algorithms used for iris recognition consider the pupil as a circular area and fit a circle to its boundary. Considering the pupil to be a circle is a method which is sensitive to the imaging condition because in the case of off angle imaging the pupil becomes an ellipse instead of a circle. In addition the pupil cannot be considered a perfect circle even if the off angle imaging is avoided. Most information in iris area exist in the collarette which is a small area around the pupil therefore a small error in detecting the pupil boundary may result in poor performance of the identification system.

The presented graph cut method uses the gray level values of pixels to compute the weights of the links in the graph. The graph has two terminals, one represents the pupil and the other one represents the rest of the image, considered as the background. The method is explained and its high performance is demonstrated by experiments based on applying the method on the CASIA eye image database.

Keywords: Graph cut, Segmentation, Iris recognition, Biometric, Energy minimization

1 Introduction

Biometric technology is the science of extracting unique physiological or behavioral features of individuals and using them for automatic identification of the individuals. Due to the increasing need for security and systems satisfying this need, lots of time and effort is spent to develop such systems. There are several security systems such as biometric based systems, keys, passwords, smart cards and etc., however those based on biometrics "i.e. unique features of individual's body" have shown more accuracy and reliability. There exist several biometrics that are currently being used for identification purposes such as face, fingerprint, palm print, iris, hand geometry and etc. Moreover among various kinds of biometrics iris recognition has proved to be the most accurate one, and attracted lots of attention during the past two decades. The first and most reliable iris recognition system was introduced by J. Daugman in 1994 [5]. After Daugman several systems were introduced and the most famous ones are the systems designed by Wildes [6], Ma [7], and Lim [8]. Despite of the varieties in these methods, all of them follow the same procedure that is comprised of four steps, segmentation, normalization, feature extraction and matching. The input for all iris recognition systems is an image which is captured from the whole eye region and not just the iris; therefore, it has a large unwanted area that must be eliminated before processing the image. Most of the algorithms consider iris region as the area between two concentric circles. Although this approximation yields relatively high recognition rate, it has an error due to off angle imaging which may cause false recognition. Off angle imaging, shown in fig. 1, occurs when the camera lens and the pupil center are not along a straight line perpendicular to the lens plate which cause the pupil and iris area no longer appear as circles. This may occurs when the head rotates or when eye rotates and the person does not look at the camera lens

(a) (b)

Fig. 1. a) Standard imaging situation, b) exaggerated ff-angle image occurred because of head rotation.

Moreover, even under the ideal imaging conditions the pupil boundary is not a perfect circle and in many cases a small area of the pupil is taken as the iris area by traditional methods. Although the captured area is small, considering the fact that most of the iris patterns exist in the collarette area - which is a small area surrounding the pupil - the error of inaccurate segmentation will be significant. Therefore a method to accurately detect the pupil boundary is highly required.

Graph cut method introduced by Y. Boykov [2] is an efficient segmentation method based on energy minimization. This method considers the image as a graph and searches for a cut in the graph that has minimum energy. The min-cut/max-flow energy minimization method is commonly used for the purpose of energy minimization [1].

Using the graph cut based iris segmentation solves the problem of off angle imaging and also the noncircularity of the pupil that is one of main sources of error in iris recognition known as pupil error. In the following section of the paper, related works performed on segmentation of eye images are presented. In section 3 a brief introduction to the theory of Graph-Cuts will be presented, in section 4 the segmentation process using the graph cuts will be described. In section 5 implementation of the method is described. Section 6 talks about the experimental results of applying the method and section 7 is the conclusion of applying the method.

2 Related Work

There is several segmentation algorithms proposed for iris recognition, in this section some of them will be reviewed and their performance will be discussed.

Daugman [9,10] proposed his segmentation algorithm using integro-differential operator that uses first derivative of the image to search for edges. This method is sensitive to noise and does not eliminate the noise of pupil i.e. the noise added to the system due to imperfection in detecting the iris boundaries. It uses two arcs to identify the upper and lower eyelids.

Wildes [6] used edge detectors and Hough transforms to segment the eye image. Also two parabolas were used to find the eyelids. The noises of pupil and eyelashes (the noise that is added to system due to loss of some portions of the iris that are occluded by eyelashes) cannot be eliminated by this method.

Tisse [11] enhanced Daugman's integro-differential method by reducing its computation time and solving the problem of locating the pupil center outside the image. The noises caused by eyelashes and pupil cannot be canceled by this method.

Ma [7] presented his method using Hough transform after filtering the image and finding the edge points. In this method the noise of eyelashes is canceled but the pupil noise exists in the segmented area.

The method presented by Kong and Zang [12], detects the iris boundary by mapping the image from Radial coordinate to Cartesian coordinate. In this method the pupil noise is not canceled but the problem of eyelashes is solved.

3 Graph Cut Theory

As mentioned before, the graph cut theory that is used to minimize the energy function defined to segment the input eye image.

Consider a graph $G = \langle V, E \rangle$ in which V is the set of nodes and E is the set of edges that construct the graph. G is called an undirected graph if the change in the cost function from one node to another, is direction independent. An example of a graph is shown in fig. 2. We define two terminals for the graph – a source (s) and a sink (t). These two terminals are the main nodes in the graph and are defined by the user. The maximum cost (weight) in the graph will be given to these terminal nodes. Nodes other than the terminals are assigned nonnegative weights being less than or equal to the weights of the two terminals. Subset C ($C \subset E$) is called a cut if it can divide V into two separate sets S and T (where T is equal to $V - S$) in a way that $s \in S$ and $t \in T$ (s and t are the two terminals of the graph). The cost of a cut is defined as the sum of the costs of its edges. The minimum cut problem or the problem of minimizing the cost function is performed by finding the cut with minimum cost or energy. Cost is defined as

$$\mathrm{cost}(C) = \sum_{e_{i,j} \in C} w_{i,j} \qquad i, j \in V \qquad (1)$$

Where $e_{i,j}$ is the edge or link connecting the two vertices i and j and $w_{i,j}$ is the weight associated with this edge. Several methods [1] have been introduced to solve the minimum cut problem in polynomial time. To segment an image using graph cut method, the pixels of the image are considered as the nodes of the graph. The edges represent the relationship between neighboring nodes or pixels and a cut represents a partitioning of the image constructed via these nodes. Finding a minimum cut for the image graph results in a partitioning of the image which is optimal in terms of the defined cost function for the cut.

4 Segmentation Technique

To segment the image, the terms of a graph such as the vertices, source, etc. are defined for the image. The pixels of the image are defined as the vertices of the graph. All neighboring pairs of pixels of the image are assumed to be connected to each other with a link and these links are called the edges. Capacity of each link is defined in terms of the sharpness of the edge existing between the pixels. The sharpness of an edge is defined by the difference between their intensity values. The label “O” or “object” can be assigned to a set of pixels to specify the source or object terminal and the label “B” or “background” can be assigned to another set representing the sink or background pixels. The goal is to find a cut or a set of edges that separates the object and the background sets in a way that the cut has the minimum cost. To perform the minimization process the cost or energy function is defined. According to [2], the general form of an energy function can be represented as (2)

$$E = \sum_{p \in P} \left(D_p(f_p) + \sum_{q \in N(p)} V_{p,q}(f_p, f_q) \right) \quad (2)$$

Where, E is the energy or the cost of the edge, N is the neighborhood formed for each pixel in which the connectivity and cost are defined. The cost or capacity of each link is measured according to the distance of the pixels and the sharpness of the edges existing between them.

The cost of assigning pixel p to the set f_p is measured by function D_p, and the cost of assigning two adjacent pixels p and q to the same set is measured by function $V_{p,q}$. Boykov [2] proved that any cut minimizing the cost, also minimizes energy defined in eq(2).

In the graph cut energy function defined in eq(2) the

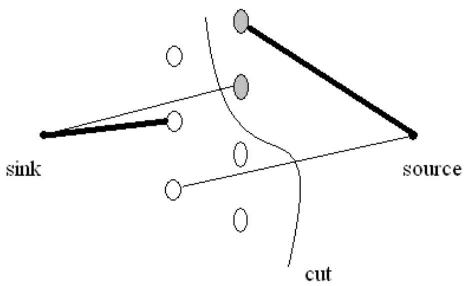


Fig.2. An example of a 2D graph showing two terminals named by “source” and “sink”, and the cut separating the regions. Thick lines connect the terminal to the pixels of the same region, while the thin lines show its connection to the pixels from the other region (only a few of the links are shown in the figure)

D_p cost function is defined as

$$D_p(f_p) = \begin{cases} \text{MAX} & p \in O, f_p = S \\ \text{MAX} & p \in B, f_p = T \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Where, Max is the large positive value that is assigned to sink and source terminals during the initial labeling process. The cost function $V_{p,q}$ is demonstrated as

$$V_{p,q} = \begin{cases} \exp\left(\dfrac{-(I_p - I_q)^2}{2\sigma^2} \right) \Big/ \text{dist}(p,q) & p,q \in N \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Where, I_p is the intensity value of the pixel p and $\text{dist}(p,q)$ is the distance between pixel p and pixel q. The term σ is the variance of pixel intensity values inside the object.

In the proposed method a σ value per cluster is calculated for the whole image and then these values will be used in the rest of the process.

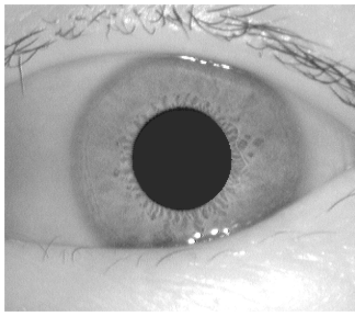


Fig. 3. Sample eye image from CASIA eye images database

5 Implementation

The described graph cut segmentation algorithm is applied to eye images that are taken for iris recognition purposes to segment the image and detect the pupil boundary precisely. Knowing the fact that pupil is a dark region in any eye, fig. 3, one can assume the gray level of its pixels to be close to zero. Since all regions of the image, except for the eyelashes and the pupil, have high gray values, there is need for the effect eyelashes in the picture. The pixels with small gray level values are marked as potential vertices to be labeled as the source or object vertices of the graph. To detect and eliminate the pixels related to the eyelashes from the pupil pixels, the method given in [13] is applied. This method uses the difference between the pixel intensity value and the mean of the gray level of its neighboring pixels to decide whether it is an eyelash pixel or not.

To do the labeling i.e. assigning the source and sink pixels, we consider two values, one close to zero to represent the source and one close to the largest gray level existing in the eye image to denote the sink or target terminal of the graph. To find these values the histogram of the image, fig. 4, is used.

A large number of pixels, corresponding to the pupil area, have intensity values close to zero. These pixels can be observed in the beginning of the image histogram, fig.4. The first peak in the histogram that represents the intensity value that has the largest number of pixels with near zero intensity value is taken as the gray level of the source terminal of the graph. To assign the intensity value of the sink terminal, the gray value of the last peak in the histogram is chosen (fig. 4).

Two cost matrices are defined to specify the cost of

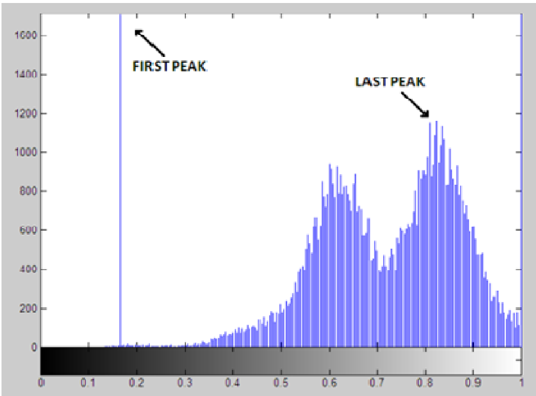


Fig. 4. Histogram of a sample image from CASIA eye images database (the image that is shown in fig. 3). The gray value of the first peak is taken as the label for source terminal and the gray value of the last peak is taken as the label for sink or target terminal

assigning each pixel to either of the clusters. In each cost matrix the highest cost (MAX) is assigned to the pixels with the same intensity value as the terminal intensity value. For other pixels, the cost is calculated based on the difference between the intensity value of the pixel and the intensity value of the terminal using the following relation

$$L_{p,terminal} = \frac{(I_p - I_{terminal})^2}{2\sigma^2} \qquad (5)$$

Where, $p \in P$, terminal $\in \{0, B\}$ and I_p is the intensity value of pixel p. Once the terminal nodes and the cost of every node in the graph are assigned, energy minimization method is applied based on the energy function defined in (2) then the cut that minimizes that function is found. The resulting cut shown in fig. 5 represents the precisely detected pupil boundary. The energy minimization is performed using the energy minimization software developed by Boykov and Olga. The software described in [3] and [4] uses the cost function and energy function that are given in equations (1) and (2) respectively. Boykov [3] develops multi-label energy minimization technique while in [4] he develops a two-label (binary) energy minimization with graph cuts. The software uses the graph construction method described in [4] and then applies the algorithm described in [3]. The software performs the energy minimization process using a fast min-cut/max-flow algorithm developed by Boykov and Kolmogorov [1]. The algorithm only uses the "forward star" method that is introduced in [1]. In order to implement the method in MATLAB environment, the work done by Bagon [14] was also used.

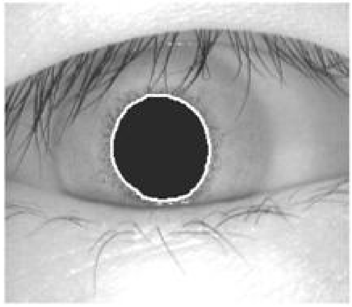


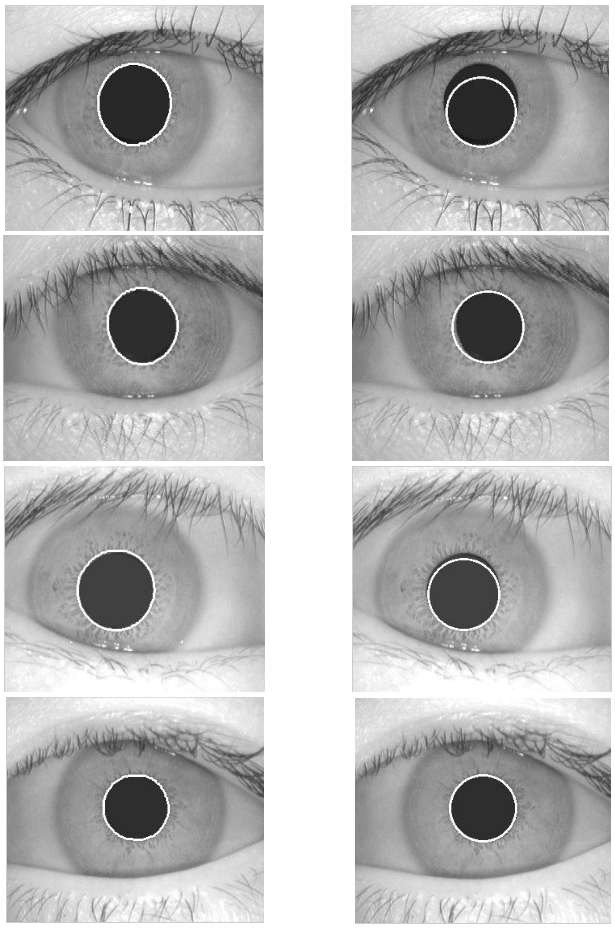
Fig. 5. Pupil boundary detected for a sample eye image. Clearly, the pupil boundary does not have a specific shape (e.g. circle or ellipse) that is a problem for most of the iris segmentation algorithms.

6 Experimental Results

The new algorithm was applied to the images of the CASIA eye image database. CASIA image database is collected by the Chinese Academy of Science – Institute of Automation and has 756 eye images from 108 individuals. These images are acquired under infrared light, therefore they are gray images, and have no reflection of the environment. The segmentation process in average takes 2 seconds to complete on a PENTIUM IV pc with 1.66 GHz processor and 1 GB RAM. A few sample segmented eye images are shown and compared with our previous work in fig. 6.

The method can detect the boundary regardless of the shape of the pupil, which enables us to avoid considering some parts of the pupil as iris or losing some parts of the iris because of the non-circular shape of the pupil. Most pupil segmentation algorithms assume the pupil as a circular object and try to fit a circle to its boundary.

The algorithm was tested on all the 756 images of the CASIA eye image database. All of the images were segmented successfully with high precision which proved the efficiency of the method.



(a) (b)

Fig. 6. a) Comparison of the results of the proposed method with b) the method introduced in [12]. As can be seen in case the pupil boundary is not a perfect circle the performance of the method presented in this paper is much better and the edges are detected precisely.(Graph cut based segmentation is applied to each image in the left column and the corresponding result of the method introduced in [12] is given in the right column)

7 Conclusions

A method based on graph cuts was presented to segment the pupil region in an eye image for iris recognition purposes. The method was described and also tested experimentally to confirm its usefulness.

The method was applied to the CASIA eye image database. All eye images of this database were segmented with high precision. The results were compared with our previous work on iris segmentation [13], and the new graph cut method showed great improvement in detecting the pupil boundary with high precision. This shows the efficiency of the method for iris segmentation. The comparison of the two methods for some sample eye images was shown in fig.6. In this method only the gray level information of the images was used to perform the segmentation. For future work we are working on expanding the method to detect the outer boundary of the iris and also expanding the method to color space for color images.

8 Acknowledgments

The CASIA iris image database collected by “Institute of Automation, Chinese Academy of Sciences”, and citation to CASIA Iris Database, “http:www.sinobiometrics.com".

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