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Original Research Article

A retinal image authentication framework based on a graph-based representation algorithm in a two-stage matching structure

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ABSTRACT

Retinal vascular pattern has many valuable characteristics such as uniqueness, stability and permanence as a basis for human authentication in security applications. This paper presents an automatic rotation-invariant retinal authentication framework based on a novel graph-based retinal representation scheme. In the proposed framework, to replace the retinal image with a relational mathematical graph (RMG), we propose a novel RMG definition algorithm from the corresponding blood vessel pattern of the retinal image. Then, the unique features of RMG are extracted to supplement the authentication process in our framework. The authentication process is carried out in a two-stage matching structure. In the first stage of this scenario, the defined RMG of enquiry image is authenticated with enrolled RMGs in the database based on isomorphism theory. If the defined RMG of enquiry image is not isomorphic with none enrolled RMG in the database, in the second stage of our matching structure, the authentication is performed based on the extracted features from the defined RMG by a similarity-based matching scheme. The proposed graph-based authentication framework is evaluated on VARIA database and accuracy rate of 97.14% with false accept ratio of zero and false reject ratio of 2.85% are obtained. The experimental results show that the proposed authentication framework provides the rotation invariant, multi resolution and optimized features with low computational complexity for the retina-based authentication application.

1. Introduction

In the recent years, there has been a great demand for accurate identification of human in information technology and high security applications such as attendance system, airport and police station security. In order to identify individuals for these applications, biometric identifiers based on somatic or behavioral specifications such as face, fingerprint, palm print, iris, voice, DNA and retinal are usually employed [1]. The biometric identifiers require being unique, measurable and repeatable for every individual to distinguish between people in

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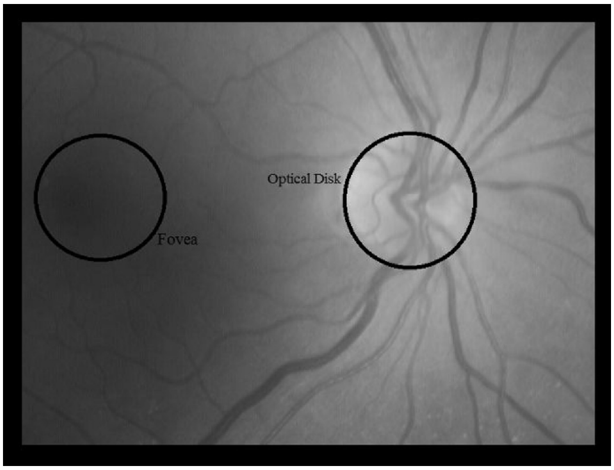

Fig. 1 – A fundus retinal image from VARIA database.

the storage database. The pattern of blood vessels in the human retinal has provided the higher level of individuality and security duo to its robustness against impersonation, universality, less modification during the life, stability over time and individuality for each person (even in identical twins). In addition to the blood vessels in a retinal image, optical disk (OD) and fovea regions are two important properties in the retinal images. Fig. 1 shows these regions in a fundus retinal image.

In the retina-based human authentication systems, there are three major challenges including, low contrast, non-uniform illumination conditions and the movements of head and eye during image capturing. Therefore, to overcome to these challenges, the introduced retina-based authentication algorithms require to be robust to rotation of the retinal image and intensity variations. Besides, the false accept ratio (FAR) in an authentication system is a main measure of security for the employed system. Hence, FAR is one of the factors which are considered in designing the introduced authentication system.

An authentication system based on retinal images requires unique features for each individual which can be extracted from the vessel patterns of the fundus image. The feature extraction techniques can be investigated in transform and spatial domains. In the transform domain, the features are extracted from 2D Fourier, Hough, curvelet and wavelet transforms of the image [2–5] while in the spatial domain, the features are obtained from the structure of retinal image such as the position of OD, the number of bifurcations and vessel end points, length, width and shape of the vessels [6–12].

The transform domain techniques are usually employed to reduce the effect of rotation and also provide energy-based analysis for the authentication. For example, in [12] the polar coordinates and wavelet transform were used to obtain the robust features relative to rotation. Also in [2], a tessellation technique in the frequency domain was used to calculate the power from the binary image of vascular pattern due to provide the invariant and robust to rotation features. Moreover, the authors in [9] combined Harris corner detector with a phase correction algorithm for extracting the robust features. However, this method was sensitive to the noise and illumination of original image.

The spatial domain techniques are typically applied on the enhanced images to extract features with morphological operators. For example, in [6], angular partitioning of vascular pattern was applied to obtain the feature vector. In another work, fractal dimension using box counting algorithm into the vessel skeleton was applied [13]. Although the feature extraction techniques in the spatial domain are easier than to implement, their performance degrades in the presence of rotation, displacement and contrast in the sample image. Both the spatial and transform domains of feature-based identification algorithms face with many challenges including, low quality of fundus images, low accuracy of segmentation and difficulty for separating the OD and fovea regions [7,14].

Due to the limitation of both mentioned domain techniques and also designing a simple authentication framework, graph-based verification systems have been developed in [7,15–17]. These techniques are based on the representation of the blood vessel patterns by graphs and the identification of individuals by matching the corresponding graphs. The graph-based techniques are usually used the extracted vascular pattern and a graph matching algorithm to identify the individuals. For example, the authors in [7] proposed a verification system based on biometric graph matching (BGM) with the high range of separation between imposter and genuine data by incorporating the vertex, edge sets and vertex labeling in the Cartesian map of the vascular pattern. However, this definition of the spatial graph is much more complex in compare with other methods such as adjacency and Laplacian matrix. Moreover the retina graphs were extracted manually to prevent noise in the feature extractor algorithm [15]. In another work, an undirected vascular structure graph was constructed through the graph nodes and edges to corresponding between pairwise vascular feature points [17]. However, the authors in [17] claimed that more investigations require finding a robust graph representation of the retinal image. Moreover, the authors in [18] presented *K*-nearest neighbor graph (K-NNG) to register a graph from the retinal image where non-direct edges were obtained from their closest nodes. The performance of this method was degraded by selecting inappropriate value of *K*, when a vertex was not in its closest neighbors. In other words, this method is a semi-automatic graph registration technique.

With regard to described studies in above, it is required to develop an approach which not only overcomes the limitation of spatial and transform features but also increases the robustness of graph registration algorithm of the retinal images in an automatic manner. In this paper, to obtain a simple and robust graph representation of the vascular pattern and overcome the complexity of feature extraction in the special and transform domain authentication techniques, we develop a framework for graph-based retinal authentication system where the mathematical graph is represented by an adjacency matrix. This approach requires an accurate tracing of the retinal vessel tree in an automated manner. Hence, we propose relational mathematical graph (RMG) definition algorithm to obtain the adjacency matrix automatically with high accuracy. Then, the verification task is developed with the extracted features from the adjacency matrix such as isomorphism and spectral graph properties. These features allow us to use unique, reliable and repeatable features for the

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