AN AUTOMATIC IRIS RECOGNITION SYSTEM BASED ON FRACTAL DIMENSION

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Abstract

Recent advancements in computer hardware and software technology have enabled industry to develop affordable automated biometrics-based authentication systems. Since human iris possesses very complex texture pattern, a novel approach based on fractal dimension for recognizing the iris of the human eye is presented in this paper. Fractal dimension values of iris blocks are computed by using five different fractal dimension estimate algorithms and two recognition techniques are employed to identify iris patterns for personal authentication. A prototype system, named Automated Iris Recognition System-AIRS, has been developed and simulation results are given.

1. INTRODUCTION

Traditionally, the methods for personal authentication are based on what a person possesses (e.g., key, ID card, etc.) or what a person knows (e.g., secret password, PIN number, etc.). However, these methods usually have the following problems. For example, keys may be falsified, ID cards may be lost, and passwords and PIN numbers may be forgotten. Accurate and reliable personal authentication (or identity authentication) is becoming more and more urgent to the operation of cybernetic society [1],[2]. Recent advancements in computer hardware and software technology have enabled academy to research and industry to develop affordable automated biometrics-based authentication systems. *Biometrics*, which refers to automatic identity authentication of a person on a basis of his or her unique physiological or behavioral characteristics, is inherently more reliable and more capable in discriminating between an authorized person and a fradulent impostor than traditional methods. These systems are now used in a wide range of environments, such as law enforcement, social welfare, banking, e-commerce, and various security applications. Many biometrics, including fingerprints, hand geometry or palmprints, facial features, iris, retina, handwriting signature, voice, and DNA, have been used for the authentication of individuals [4]-[11]. A brief comparison among these techniques was given in [1],[2].

Basically, a biometric system is essentially a pattern recognition system which makes a personal identification by determining the authenticity of the specific physiological or behavioral characteristic possessed by the user. The automated biometrics-based systems are typically classified into two major categories: *one-to-one* (or *verification*) systems and *one-to-many* (or *identification*) systems [1]. Accurate automatic personal identification is critical in a wide range of application domains such as (i) military applications, (ii) forensics applications: criminal identification and personal security, and (iii) civilian applications: national ID card, passport, smartcard, e-commerce, automated banking, computer login systems, home security systems, restricted entry, ATMs, credit cards, Internet access, corporate networks, airport access control, government benefits distribution, customs and immigration, confidential databases, etc [3].

In principle as well as in practice, any human physiological and behavioral trait can be employed to make a personal identification in which it satisfy the following requirements such as high universality, high uniqueness, high permanence, high cellectability, high performance, high acceptability, and high circumvention. Most of the existing methods have limited capabilities in recognizing relatively complex features in realistic practical situations. In recent years, iris feature of human eye is receiving growing interests due to its inherence of high uniqueness, high permanence, and high circumvention. In this paper we will investigate and design an automated biometric recognition system based on the iris feature.

2. REVIEWS

2.1 Characteristics of Human Iris

The potential of the human iris for biometric authentication comes from the anatomy of the eye [12],[13]. Iris, as shown in Fig. 1, is a kind of physiological biometric feature, contains unique texture pattern, and is highly complex enough to be used as a biometric signature [13]. This characteristic shows that the probability of finding two persons with identical iris patterns is almost zero. Compared with other biometric features such as hand and fingerprint, iris patterns are more stable and reliable. It is unique to people and stable with age [13],[14]. Several studies have shown that normal variations in coloring and structure of the tissues of the iris are so multitudinous that there are not ever two irises alike, not even for identical twins [13]. Even for a single person his two irises are also different. Furthermore, iris recognition systems can be non-invasive to their users. As a result, iris feature is a very good candidate for biometric authentication.

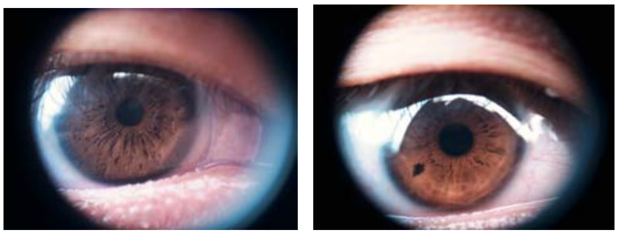

Fig. 1. Two examples of iris images.

2.2 Previous Works

Nowaday, the iris is the focus of a relatively new biometric means of authentication. After Flom and Safir [14] observed the fact that every iris has a highly detailed and unique texture that remains stable over decades of life, they proposed the concept of automated iris recognition in 1988, however, finally not realized.

Early work toward actually realizing an automated iris recognition system was carried out by Johnson in 1991 [15]. Later, a successful system by using 2-D Gabor wavelet transform was developed by Daugman [16]-[18]. The basic principle of Daugman's approach is that it converts the images into a representation invariant to differences in rotation and scale, filters the resulting images with oriented, quadrature pair, bandpass filters, and coarsely quantizes the resulting representation for bit-wise matching. In this system, the visible texture of a person's iris in a real-time video image is encoded into a compact sequence of multi-scale quadrature 2-D Gabor wavelet coefficients, whose most significant bits consist of a 256-byte "iris code." Daugman claimed that his system has excellent performance on a diverse database of many iris images. In 1996, Wildes, *et al*., developed a prototype system based on automated iris recognition which uses a very computationally demanding image registration technique [19]-[21]. This system uses an isotropic bandpass decomposition, e.g., Laplacian pyramid, to decompose the image data into multi-scale representation. They have shown promising performance on diverse databases of hundreds of iris images.

Recently, three approaches based on multiresolution analysis have been conducted. Boles and Boashash [22],[23] proposed an iris identification system in which zero-crossing of the wavelet transform at various resolutions are calculated over concentric circles on the iris, and the resulting 1-D signals are compared with the model features using different dissimilarity functions. Zhu, Tan, and Wang [24] proposed an algorithm for global iris texture feature extraction using multi-channel Gabor filtering and wavelet transform. The mean and standard deviation of each sub-image at different resolutions are extracted as the features. It uses only a few selected resolutions for matching, thus making it computationally efficient and less sensitive to noise. The work in [25] also uses wavelet multi-resolution analysis based on Gabor filtering for iris feature extraction. Finally, two excellent review articles [26],[27] are valuable to refer.

3. AN AUTOMATIC IRIS RECOGNITION SYSTEM---AIRS

3.1 Overview of the AIRS System

Since human iris possesses very complex texture pattern, in order to use the iris pattern for authentication, it is significant to define a representation that is well adapted for extracting the iris information content from the images of human eye. In this paper, we propose a novel algorithm for extracting unique features from the images and representing these features using the fractal dimensions. The iris code representing the fractal dimension is then used to recognize individuals. The entire system architecture of the automated iris recognition system---AIRS--- we propose in this paper is illustrated in Fig. 2. The AIRS system is composed of four major modules: ***image acquisition*** module, ***preprocessing*** module, ***feature extraction*** module, and ***pattern recognition*** module.

In the first module, an image containing the user's eye is captured and a suitable color image is selected. Next, the preprocessing module performs three major tasks including segmentation, normalization, and enhancement for the captured iris image. Then, the feature extraction module decomposes the iris area into some small blocks, and computes the fractal dimension for every block to generate iris feature code. Finally, two pattern-matching techniques such as K-means and neural network are employed on the iris feature code to recognize the iris patterns.

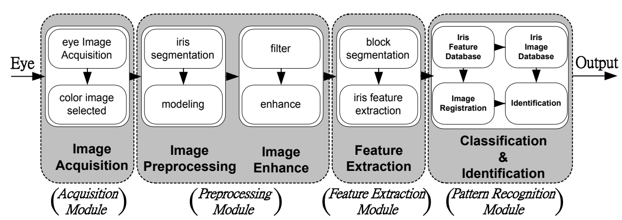

Fig. 2. The entire system architecture of AIRS.

3.2 Image Acquisition Module

3.2.1 Iris Image Acquisition Unit

Since iris is small in size and dark in color (especially for Asian peoples), it is difficult to acquire pure images for recognition using low resolution CCD camera. We adopt a digital camera with a resolution of 1,600×1,200 pixels without flashlight. In addition, a ×24 60mm optical enlargement lens and a 13-watt light are also arranged to capture a good quality image in the system. The mechanism realization of the AIRS is shown in Fig. 3.

Fig. 3. The mechanism realization of AIRS system.

3.2.2 Color Selection Unit

In studying the characteristics of the irises, we will only deal with samples of the red-component profile and use these to construct a representation. Therefore, in this system, we select the image with only red-component image, shown in Fig. 4(d), rather than color image or gray-level image because it possesses the very clear detailed structure of the iris (see Fig. 4).

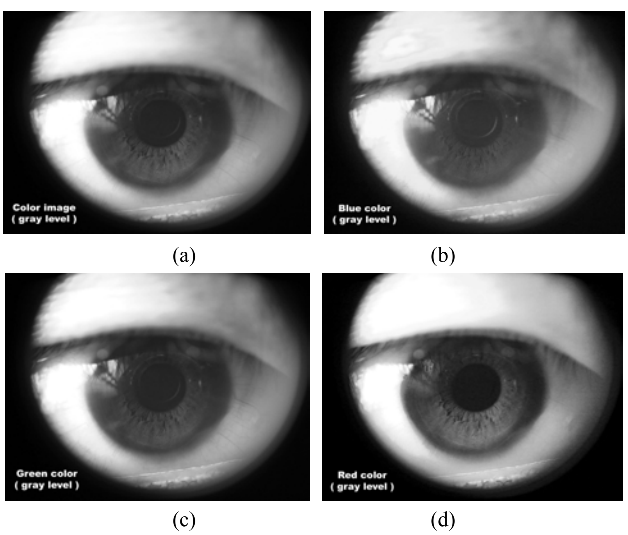

Fig. 4. (a) Color image. (b) Blue component. (c) Green component. (d) Red component.

3.3 Preprocessing Module

Before extracting the features of the iris, the image must be preprocessed to localize and segment the useful portion of the iris, to normalize the scale and illumination variation of the segmented iris, and to enhance the iris image for good for the feature extraction. Hence, the preprocessing module is composed of three units: iris image segmentation, iris image normalization, and iris image enhancement. Each unit is described as follows.

3.3.1 Iris Image Segmentation Unit

First, input images are preprocessed to extract the portion containing the iris. Both the inner boundary (i.e., the pupil boundary) and the outer boundary of a typical iris can be taken as circles. However, the two circles are usually not concentric. Compared with the other part of the eye, the pupil is darkest and the iris is dark gray. The iris image segmentation unit segments the near-circular iris area by using the following steps.

A. Positioning of Pupil

Having known that the iris and pupil have circular shapes, the edges defining the their boundaries are connected to form a closed contour. Any point within the detected pupil can be chosen as the fitting point of the procedure for extracting the iris and pupil boundaries. For positioning the dark pupil area, we search any such point within the pupil area as the fitting point. The procedure goes through the eye image via a circular mask, as shown in Fig. 5, to find some small regions with the least mean values [28]. Then the one with the minimum variance selected from those regions is specified as the fitting point.

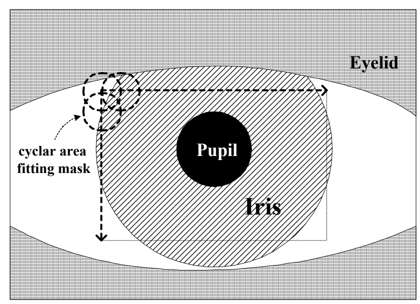

Fig. 5. Illustration of pupil outer boundary positioning.

B. Pupil Boundary Detection

Starting from the fitting point, the system is going to detect three edge points on the pupil boundary by using a three-pass process, as shown in Fig. 6. The process adopts the Prewitt's differentiation mask, expressed as

$$(x_0, y_0) = \max_{(x,y)} \left| G * \tfrac{\partial}{\partial r} I(x,y) \right| ,$$

on three directions, left, right, and down, to specify three points. Following the same process, the three edge points on the iris outer boundary are also detected.

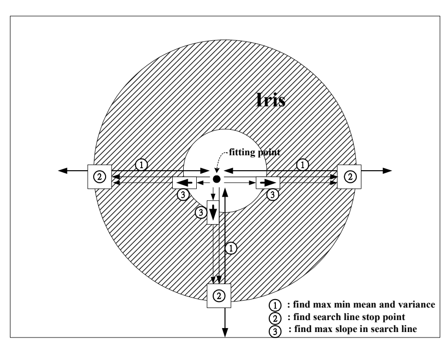

Fig. 6. A three-pass process for detecting three edge points.

C. Iris Location Parameters Computation and Iris Segmentation

As the three edge points on the pupil boundary are specified, the pupil boundary can be localized. Similarly, the location parameters of the iris can be computed via the three edge points on the iris outer boundary. In the next step, the system segments the iris. Fig. 8(b) shows an example of the iris image segmented from the original eye image in Fig. 8(a).

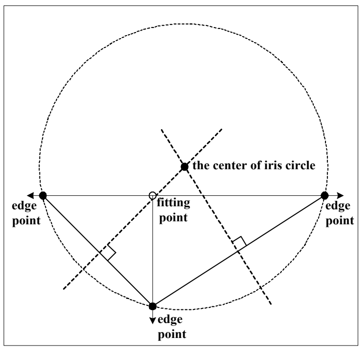

Fig. 7. Computation of the iris location parameters.

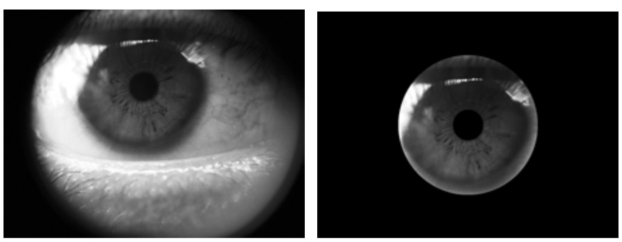

Fig. 8. Example by localizing an iris image.

3.3.2 Iris Image Normalization Unit

Under some circumstances, the brightness is not uniformly distributed. In addition, different eye-to-camera distances may result in different image sizes of the same eye. Since the size of the pupil may vary due to the variation of the illumination and the size of the iris may vary due to the distance of shot, the associated elastic deformations in the iris texture may interfere with the results of pattern matching. For the purpose of matching or recognizing the irises accurately, it is necessary to compensate the deformation via an iris normalization process. The iris image with the larger pupil must be shrunk and the smaller and vice versa. Before performing the normalization, the iris image must be transformed from rectangular coordinate space into polar coordinate space. In this system, the iris image normalization process is realized via a linear transformation along with the radial direction on polar coordinate space. All of the iris images are transformed to having the same radius of pupil. Fig. 9 shows examples of two normalized iris images.

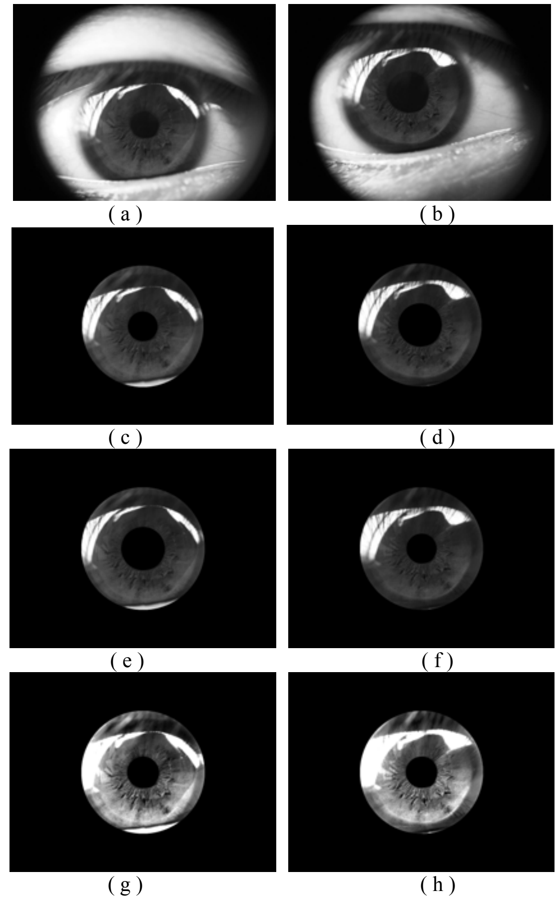

Fig. 9. Examples of two normalized iris images.

3.3.3 Iris Image Enhancement Unit

The original iris images usually have low contrast and may have non-uniform illumination caused by the position of the light source. These situations may lessen the effect of feature extraction and thus weaken the result of the iris texture analysis. In this system, we employ a high-pass filtering followed by a high frequency image enhancement to enhance the iris images so that their features may be extracted thoroughly.

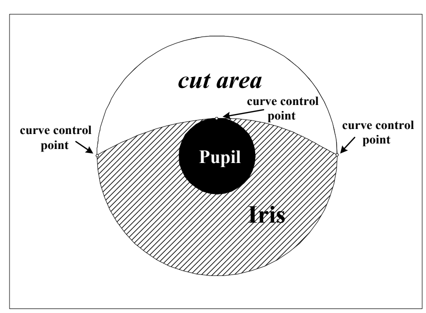

Fig. 10. Cutting the useless area.

A. High-Pass Filtering

The acquired image always contains not only the useful area of iris but also the useless area covered by eyelash and some irrelevant parts (e.g., eyelid occlusion, pupil, etc.). The system only needs to process the useful area by cutting and discarding upper part of iris, as shown in Fig. 10. Then, a high-pass filter is used to enhance the detail of the iris texture.

B. High Frequency Image Enhancement

In order for making the dynamic range of the iris feature values wider, a high frequency image enhancement, as shown in Fig. 11, is performed. Fig. 12 shows the example of iris images after image enhancement.

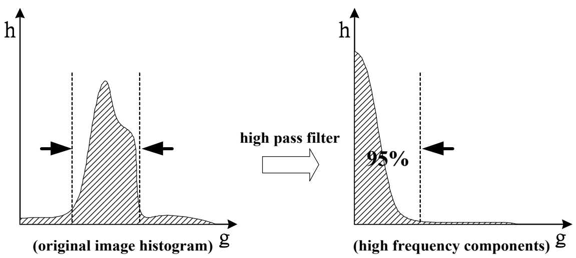

Fig. 11. High frequency image enhancement.

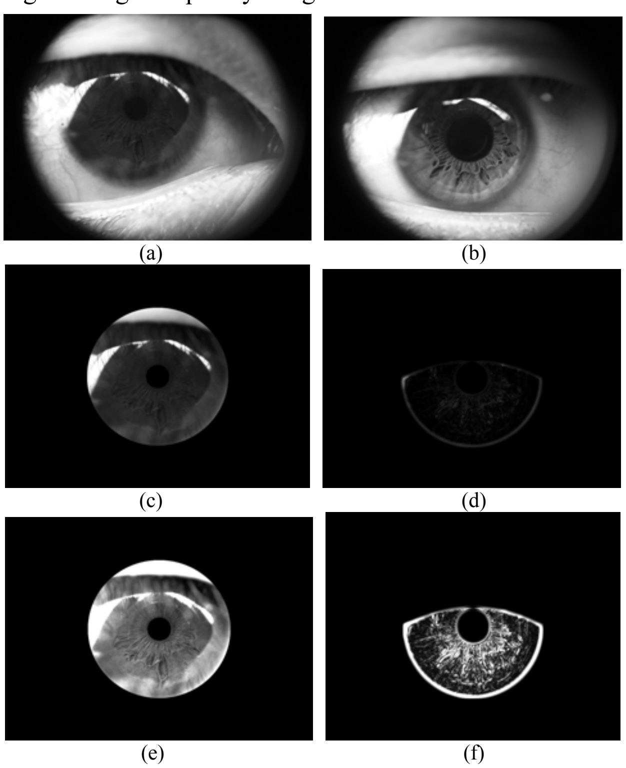

Fig. 12. Example of iris images after image enhancement.

3.4 Feature Extraction Module

The task of this module is to extract the features representing the iris image patterns for the following recognition process. Since human iris possesses very complex texture pattern [29],[30], in this paper we utilize the fractal dimension [30],[31] to represent the feature of the iris.

3.4.1 Iris Block Segmentation Unit

Since the typical fractal dimension estimation methods are squared-block-based, we must segment the iris area into small overlapping blocks, each having fan geometry. An example of iris block segmentation is shown in Fig. 13. The number of blocks is selected to be 64 in this system. In order to compute the feature values, the geometries of iris blocks must be transformed from fan to square, as shown in Fig. 14.

3.4.2 Iris Block Fractal Dimension Estimate Unit

This unit computes the fractal dimension for each of 64 iris blocks as the iris feature. In this paper, five different estimate algorithms, including the differential box-counting (DBC) algorithm [32], shifting differential box-counting (SDBC) algorithm [33], scanning box-counting (SBC) algorithm [33], RD algorithm (for correlation dimension), and HCALC algorithm [31], are employed to compute the fractal dimension. The system computes five fractal dimension values, each with 8 bits, for each iris block, thus totally an iris code of 64×5×8=2,560 bits will be generated for each iris image.

Fig. 13. Example of iris block segmentation.

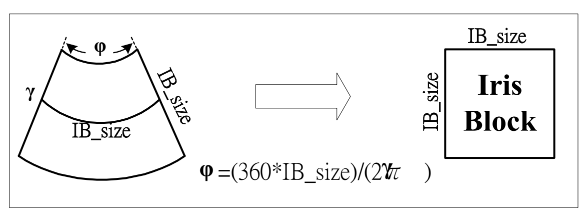

Fig. 14. Iris block geometry transformation from fan to square.

3.5 Iris Pattern Recognition Module

Iris recognition based on given feature vectors is a typical pattern recognition problem. Thus, finally the iris pattern recognition module is performed in which a decision is made by means of pattern matching. Having localized the region of an acquired image that corresponds to the iris and having generated a sequence of iris code of the iris image through computing the fractal dimension for each iris block of the iris image, the final task of the system is pattern recognition process. The pattern recognition module decides if this pattern matches a previously stored iris pattern from an iris image database. In this paper, two typical pattern recognition techniques such as K-mean [34] and neural network approachs [35],[36] are employed.

4. SIMULATION AND RESULTS

Based on the algorithms and procedures discussed above, a prototype of this automated iris recognition system, named Automated Iris Recognition System-AIRS, has been designed and implemented. In order to evaluate the performance of the AIRS system, a number of real iris images are captured and tested.

4.1 Testing Environment

In the experiment, a total number of 120 iris images captured from right eye of 40 volunteers are collected. Among them, 80 iris images are stored in the image database as the registered patterns and the remaining 40 iris images are used as the test patterns. Each image is rotated to generate three different images. This makes our method translation, rotation and scale invariant.

4.2 Evaluation Criteria

No metric is sufficiently adequate to give a reliable and persuasive indication of the recognition accuracy of a biometric system. An end-user is interested in determining the recognition performance of the biometric system for his specific application. A decision made by a biometric system is either an *authentic individual* type or a *faker individual* type. For each type of decision, there are two possible outcomes: *true* or *false*. Thus, there are a total of four possible outcomes: (i) an authentic individual is accepted, (ii) an authentic individual is rejected, (iii) a faker individual is rejected, and (iv) a faker individual is accepted. In principle, we can use the *false (faker) acceptance rate* (FAR), the *false (authentic) reject rate* (FRR) and the *equal error rate* (EER) to indicate the recognition accuracy of a biometric system.

4.3 Preliminary Analysis

Fig. 15 demonstrates the actual distributions of observed average hamming distances between unrelated iris codes (i.e., fakers) and between pairs of different iris codes for each given iris (i.e., authentics). For the case of faker, the hamming distance is a Gaussian distribution with the mean $\mu \in (50, 86)$ and the variance $\sigma^2 \approx 10$. On the other hand, for the case of faker, the hamming distance is also a Gaussian distribution with the mean $\mu \in (10, 20)$ and the variance $\sigma^2 \approx 10$. The analysis reveals that the iris feature code based on the fractal dimension is suitable for recognizing the human irises.

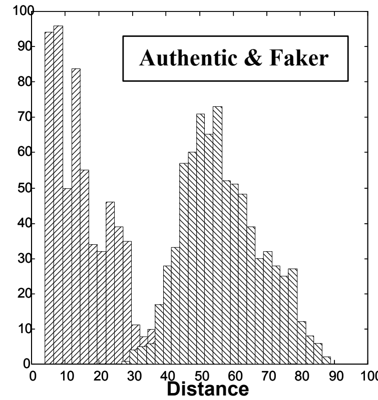

Fig. 15. Hamming distances between unrelated iris codes (i.e., fakers) and between pairs of different iris codes for each given iris (i.e., authentics).

4.4 Recognition Performance

Fig. 16 demonstrates the recognition result obtained by using the hybrid FD estimate algorithm and the K-mean recognition method. Table 1 demonstrates the recognition result obtained by using neural network recognition approach.

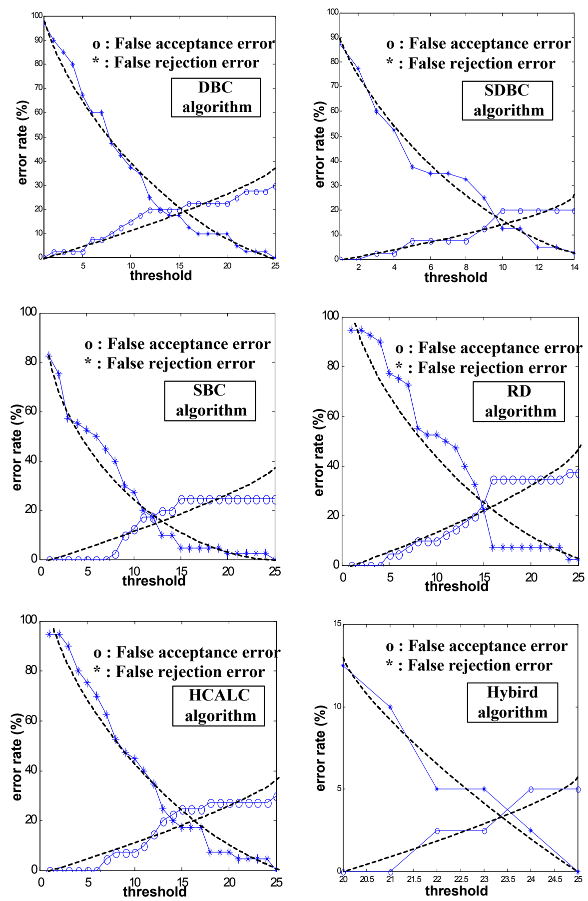

Fig. 16. The recognition results obtained by using six FD estimate algorithms and the K-mean method.

Table 1. The recognition result obtained by using neural network approach.

	AF (%)	RF (%)	RA (%)	AA (%)
DBC	7.5	92.5	50.0	50.0
SDBC	2.5	97.5	52.5	47.5
SBC	7.5	92.5	62.5	37.5
RD	12.5	87.5	62.5	37.5
HCALC	7.5	92.5	77.5	22.5
Hybrid	0	100	35.0	65.0

5. CONCLUSION

In this paper, a novel approach based on fractal dimension as the feature for recognizing the iris of the human eye is presented in this paper. Fractal dimension values of iris blocks are computed by using five different fractal dimension estimate algorithms and two recognition techniques are employed to identify iris patterns for personal authentication. A prototype system, named Automated Iris Recognition System-AIRS, has been developed and simulation results are given.

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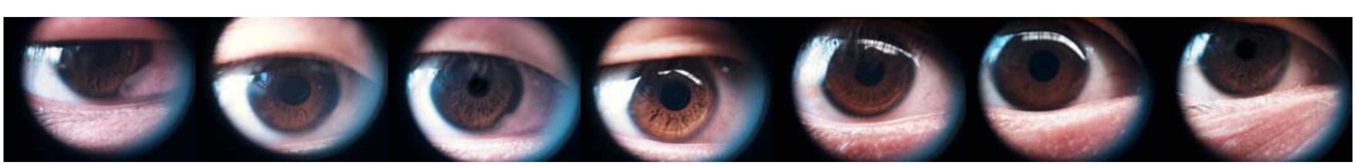

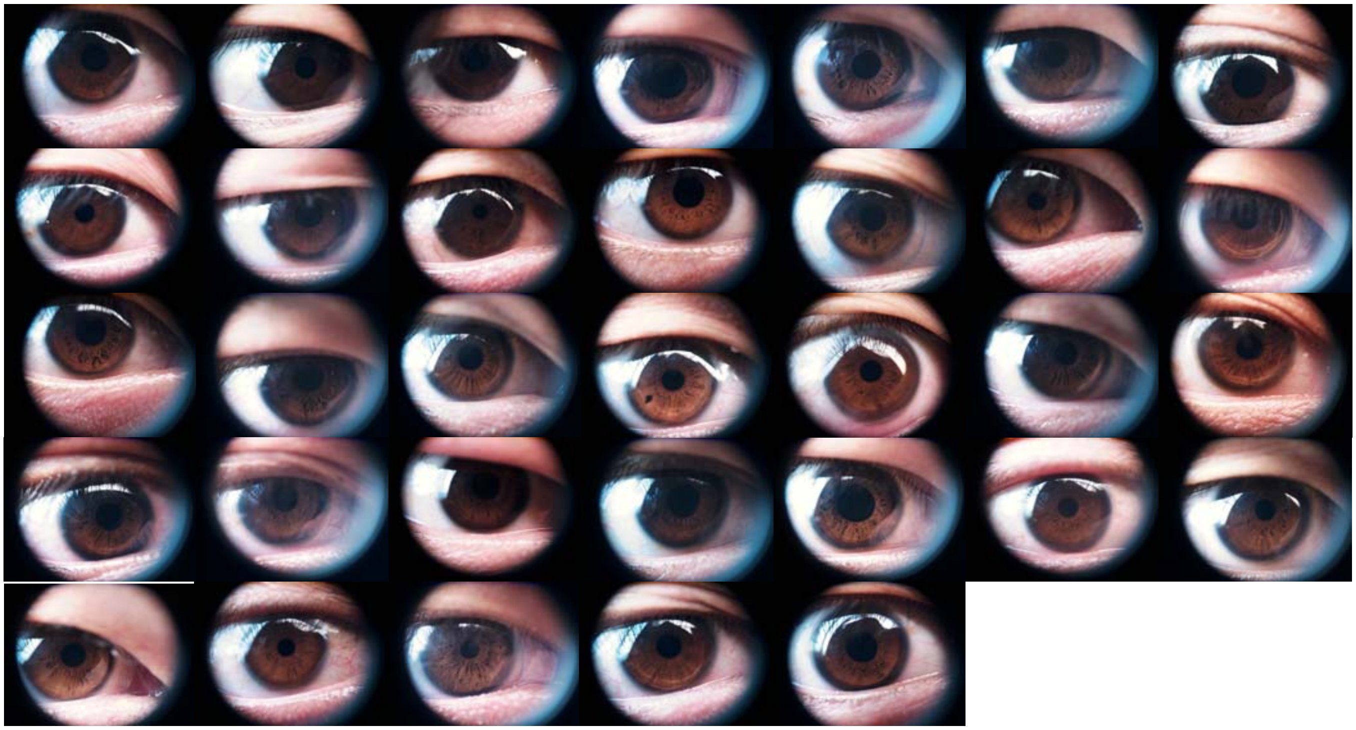

Fig. 17. The test iris database with 40 human iris patterns.

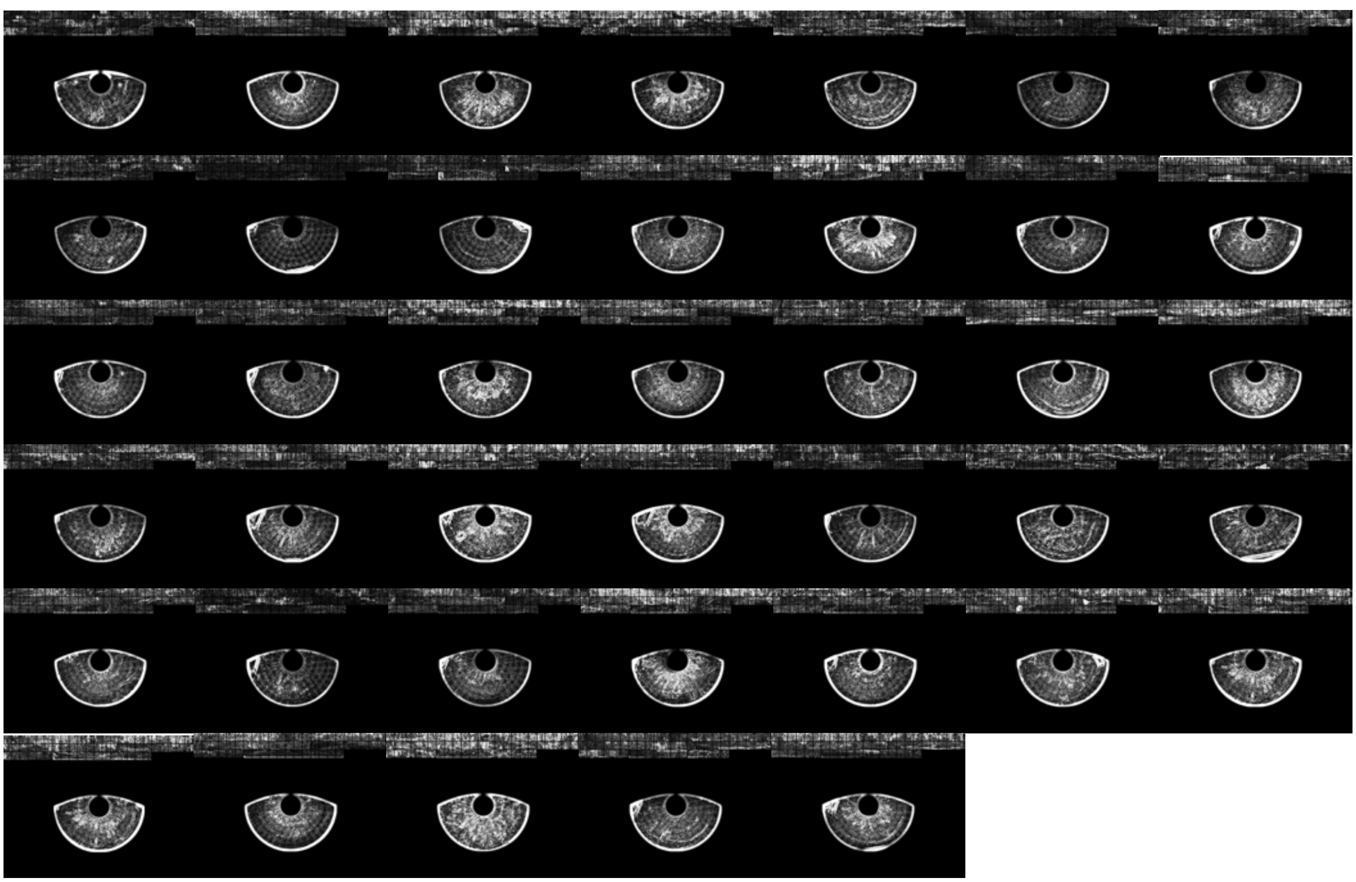

Fig. 18. The corresponding iris images after processed.