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Review

A review on advances in iris recognition methods

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Iris recognition is one of the most accurate identity verification systems. Since its initial introduction by J. Daughman, many methods have been proposed to enhance the performance. We present an overview of the latest research on iris recognition by categorizing the research in four groups outlined as localization, segmentation, coding and recognition. We present the latest developments explaining advances to solve problems existing at each of iris recognition stages.

Key words: Biometrics, identity verification, iris recognition, pattern recognition, iris segmentation, iris localization and iris code.

INTRODUCTION

Iris background

Identity verification and identification is becoming increasingly popular. Initially fingerprint, voice and face have been the main biometrics used to distinguish individuals. However, advances in the field have expanded the options to include other biometrics such as iris, retina, ear, vein, gait, smell and more. Among the large set of options, it has been shown that the iris (Daugman, 2004) is the most accurate biometric. We aim at presenting the latest advances that resolve common problems associated with iris recognition.

The iris is the elastic, pigmented, connective tissue that controls the pupil. The iris is formed in early life in a process called morphogenesis where it begins to form during the third month of gestation (Kronfeld, 1962). The structures creating its striking patterns are developed in the eight month (Wolff, 1948), although pigment accretion may continue into the first postnatal years. Once fully formed, the texture is stable throughout life while the pattern becomes permanent after puberty. The iris of the eye has a unique pattern, from eye to eye and person to person. Each iris is a meshwork of melanocyte and fibroblast cells (Johnston, 1992). The colour depends on the density of the cells and the concentration of pigment. Contrary to blue eyes, brown eyes have high cell densities and large amounts of pigmentation. The layers of the iris have both ectodermal and mesodermal origin, consisting of (from back to front): a darkly pigmented epithelium; pupillary dilator and sphincter muscles; a vascularized stroma (connective tissue of interlacing ligaments containing melanocytes); and an anterior layer with a genetically determined (Imesh et al., 1997) density of melanin pigment granules. The combined effect is a visible pattern displaying distinctive features such as arching ligaments, crypts, ridges, and a zigzag collarette (Figure 1).

The richness, uniqueness, and immutability of iris texture, as well as its external visibility, make the iris suitable for automated and highly reliable personal identification. This means that the probability of finding two people with identical iris patterns is almost zero (Daugman and Downing, 2001b). Although the iris stretches and contracts to adjust the size of the pupil in response to light, its detailed texture remains largely unaltered apart from stretching and shrinking. Such distortions in the texture can readily be reversed mathematically in analyzing an iris image, to extract and encode an iris signature that remains the same over a wide range of papillary dilations. These unique features of the iris present it as the best biometric identification method. Besides its use as a biometric identification feature, iris code has also been used as a secret key. Ziauddin and Dailey (2010) generate a biometric secret key based on an iris code. They manipulate the key information using error correcting codes that increase reliability and robustness of the system. The resulting system has a higher security rate compared to crypto-graphy based keys.

There are few papers surveying the latest work on iris recognition. Daugman (2007) attempts to survey the advances in iris recognition in a detailed mathematical

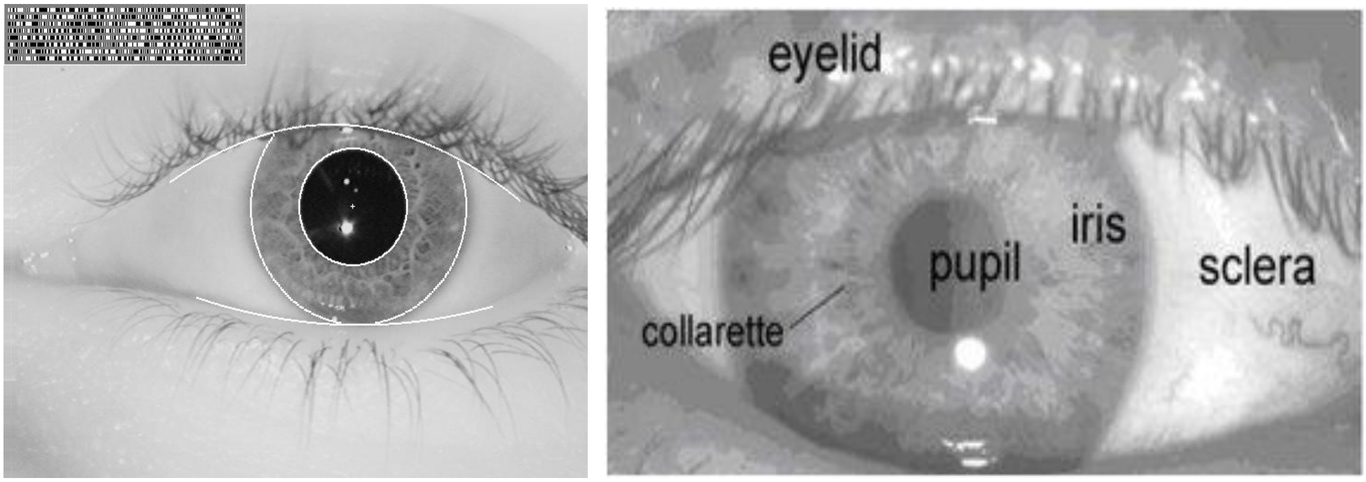

Figure 1. A sample of an iris of a human.

analysis of how some problems were solved. He discusses methods for detecting and modeling the iris inner and outer boundaries with active contours, leading to more flexible embedded coordinate systems, Fourier-based methods for solving problems in iris trigonometry, statistical inference methods for detecting and excluding eyelashes and exploring of score normalizations. Ng et al. (2008) present a survey on different iris recognition methods with an emphasis on methods that improve speed and accuracy. They also discuss benchmark databases. Popescu-Bodorin and Balas (2010) presents an overview of major algorithms where they present a tabular comparison of methods used at each of the three stages by 16 prominent papers. They show that good alternatives to Daugmans method exist. Popescu-Bodorin and Balas (2010) presents three artificial intelligence challenges in iris recognition systems: to build an exploratory supervised intelligent agent for iris recognition; to build at least a rudimentary control unit enabling an exploratory agent to act independently based on its own decisions; and describe radial iris movement through approximate equations formulated in the framework of discrete image topology. New recognition results based on the first publicly available set of processing tools for University of Bath Iris Image Database (UBIID) are also presented.

In this paper, we present the latest developments explaining advances to solve problems associated with image acquisition such as non-frontal face images and off angle iris. Problems at the segmentation stage such as iris boundary detection problems, ghosts caused by visible light, degraded system performance due to noisy iris images, and many problems due to inaccuracies at earlier stages. We also discuss advances that lead to improvement in iris system performance, improvement in iris coding methods, and improvement in recognition methods. We also present a review on a comparative study of different iris methods to find the effect of different parameters on the recognition rate, and to find an answer to the question of which approach is most suitable for extracting iris features.

Subsequently, in primary iris recognition systems present the initial work of J. Daugman and the proposed modifications. The other parts of the work present the latest research on iris categorised according to the four stages of the iris recognition system localization, segmentation, coding and recognition, followed by performance enhancement and the paper is then to concluded.

Primary iris recognition systems

Daugman (1993) presented a prototype system for iris recognition and reported that it has excellent performance on a diverse database of many images. Daugman (1994) also proposed a system for automatic identification of persons based on iris analysis. First, the system acquires through a video-camera a digitized image of an eye of the human to be identified. Then, it isolates the iris if it is present within the image and defines a circular pupillary boundary between the iris and pupil portions of the image, and it defines another circular boundary between the iris and sclera portions of the image, using arcs that are not necessarily concentric with the pupillary boundary. Then the system establishes a polar coordinate system on the isolated iris image, the origin of the coordinate system being the centre of the circular pupillary boundary. It then defines a plurality of annular analysis bands within the iris image, these analysis bands excluding certain pre-selected portions of the iris image likely to be occluded by the eyelids, eyelashes, or specular reflection from an illuminator. The portion of the iris image lying within these annular analysis bands is analyzed and encoded employing a special signal processing means comprising a multiscale, self-similar set of quadrature bandpass filters in polar coordinates, to generate an iris code of fixed length and having a universal format for all irises. The resulting code is stored as a reference code. Because of the universal format and length of all such iris codes, comparisons among different iris codes are efficient and simple. Specifically, a comparison between any two iris codes is achieved by computing the elementary logical XOR (exclusive-OR) between all their corresponding bits, and then computing the norm of the resulting binary vector. The result is a Hamming distance between the two iris code vectors. The universal format of iris codes also lends itself to rapid parallel search across large data bases of stored reference iris codes in order to determine the identity of an individual.

To perform an identification using the reference code, the system generates from an identification subject an identification code. Then, the system compares the identification code with the reference code, to ascertain the Hamming distance between the codes. This distance is then converted into a calculated likelihood that the two codes originated from the same iris, and hence from the same person, by computing the probability that the observed matching fraction of bits in the two codes could match by chance if the two codes were independent. A preselected criterion applied to this measured Hamming distance generates a "yes" or "no" decision and the confidence level for the decision is provided by the calculated probability. Daugman (2003b) outlines the steps of an iris recognition process as follows: Assessing the image focus, scribing specular reflections, localising the eye and the iris, fitting the pupillary boundary, detecting and fitting both eyelids, removing eyelashes and contact lens artifacts, demodulation and iris code creation, and XOR comparison of any two iris codes.

Wildes et al. (1994) described a prototype system for personal verification based on automated iris recognition. These recent prototype systems considered a number of implementation issues from the practical point of view. Both the systems of Daugman (2003b) and Wildes et al. (1994) concentrated on ensuring that repeated image captures produced irises in the same location within the image, had the same resolution, and were glare-free under fixed illumination. These requirements were essential for the accurate extraction of iris features in order for processing to be successful. The prototype of Wildes et al. (1994) relied on image registration, which is very computationally demanding. Daugman's system filters transformed images with oriented, quadrature pair, bandpass filters and coarsely quantizes the resulting representation for byte-wise matching. Both systems in Daugman (1993) and Wildes et al. (1994) have been much more extensively tested on databases of hundreds of images and have been shown to produce remarkable results.

Further, Daugman and Downing (2001b) and Daugman (2003b) presented a study where they have assessed the randomness and singularity of iris patterns, and their phenotypic distinctiveness as biometric identifiers, based on video images acquired in public trials of pattern recognition methods proposed in Daugman (1993). They have found that the probability of two different irises agreeing by chance in more than 70% of their phase sequence is about one in 7 billion. The detailed phase information was extracted from each isolated iris pattern using complex-valued two-dimensional Gabor wavelets. Also, they have compared images of genetically identical irises, from the left and right eyes of 324 persons, and from monozygotic twins. They have found that their relative phase sequence variation generated the same statistical distribution as did unrelated eyes.

A complete active system that uses the Daugman approach described in the foregoing is presented by Hanna et al. (1996), where for image acquisition a machine vision technique was used. The user stands in front of the system an image of his iris is acquired, and the identity is verified or refuted. The system consisted of a stereo pair of wide field-of-view (WFOV) cameras, a narrow field-of-view (NFOV) camera, a pan-tilt mirror allowing the NFOV to be moved relative to the WFOV, a real time vision computer, and a front end computer. The system actively finds the position of the user's eye and acquires a high resolution image to be passed to Daugman's system.

Looking at the iris recognition process from imaging to matching we can categorize the operation in 4 independent stages, as follows. An iris recognition system operates by initially localizing or detecting the iris in the image. Then segmentation techniques are applied to extract the iris from the image, this stage involves also masking to remove eyelids and eyelashes. Next Daugman's techniques are applied to convert the iris image to a unique iris code. After storage of the iris code, recognition and identification by reading the iris can be performed. Many approaches for iris identification have been proposed to improve speed and performance. To further enhance the performance some have combined results of several recognition approaches while others have used confidence measures. Attempts have been made to perform recognition at difficult conditions and to measure iris quality to increase the robustness of the identification technique.

IRIS LOCALISATION AND DETECTION

At the first stage of the iris recognition system, the iris must be detected and localized. Many researchers have studied iris recognition techniques in unconstrained environments, where the probability of acquiring non-ideal iris images is very high due to off-angles, noise, blurring and occlusion. Inaccuracies at this early stage detrimentally affect the performance at the next stages. Some methods underperform when frontal images have an angle. Perez et al. (2010) proposed a method based on particle swarm optimization (PSO) to generate templates for frontal face localization in real time. Additionally, the PSO templates in iris localization outperformed other methods.

He et al. (2010) use Adaboost for iris detection, where they adopt Haar-like features for object representation. The topological properties of the Haar-like features enhancement are used to enhance robustness of Adaboost learning.

After detection iris outer and inner boundaries must be drawn. The outer boundary may be occluded by eyelids; therefore, many methods have been presented for localizing the eyelids.

Kranauskas and Masiulis (2009) present a study on eyelid localization considering image focus for iris recognition, while Jang et al. (2008) proposes a detection algorithm that can be used to detect eyelid regions.

Min and Park (2009) propose an automatic eyelid and eyelash detection method based on the parabolic Hough model and Otsu's thresholding method. They apply the parabolic Hough transform to the normalized iris image, rather than to the original image to reduce the dimension of the parameter space and limit the parameter search range, decreasing computational load. For automatically separating the eyelash region Otsu's method is applied to the proposed feature that is obtained by combining the intensity and local standard deviation values.

SEGMENTATION

After finding an iris in the image, its boundary must be marked including the upper and lower eyelid boundaries. Next the eyelashes and reflections must be detected and removed. In less constrained environments iris recognition becomes difficult due to significant variation of eye position and size. Existence of eyebrows, eyelashes, glasses and contact lenses, and hair, together with illumination changes all make the segmentation task more difficult. Many have proposed different segmentation methods to tackle the recognition tasks. An iris segmentation method for non-ideal iris images is proposed in Jeong et al. (2010), where Adaboost is used to compensate for detection error caused by the edge detection operations. They also use colour segmentation to remove ghosts caused by visible light.

Another problem is noisy iris images which degrade the system performance. Tan et al. (2010) present an iris segmentation algorithm that achieves an optimum performance for noisy iris recognition tasks. Their method consists of different stages; initially a clustering scheme is proposed and the iris region is extracted from the non iris regions such as eyelashes, eyebrow, glass frame, hair, etc then the boundary is localized followed by a 1-D filter to tackle eyelashes and shape irregularity. Finally eyelashes and shadow occlusions are detected via a learned prediction model based on intensity statistics between different iris regions.

Labati and Scotti (2010) propose another segmentation method for noisy iris recognition that initially locates the centres of the pupil and the iris in the input image. Then two image strips containing the iris boundaries are extracted and linearized. The last step locates the iris boundary points in the strips and it performs a regularization operation by achieving the exclusion of the outliers and the interpolation of missing points. Authors in Li et al. (2010) also present a segmentation based method to detect iris in noisy images. First, the eye position and size are determined; second, in the eye region the limbic and then the pupillary boundaries are localized; third, the upper and lower eyelids are located; and finally the specular highlight is removed.

In an attempt to improve the performance of an iris recognition system, Sankowski et al. (2010) presented a segmentation approach that yielded the second in the NICE-I competition (Noisy Iris Challenge Evaluation – Part I), in which iris segmentation algorithms were evaluated and compared. The proposed stages were as follows: reflections localization, reflections filling in, iris boundaries localization and eyelids boundaries localization. These stages were a combination of methods proposed by the authors and methods proposed by others and improved by the authors.

Proença and Alexandre (2010) present an analysis of the relationship between the segmentation inaccuracy and the increase in the error rate of the iris recognition method. They recommend the development of methods that detect inaccurate segmentations.

IRIS CODING

Following the segmentation of the iris image, it is coded and stored at the registration stage or compared to a stored one at the identification or recognition stage. As outlined in Iris localisation and detection, Daugman was the first to present a prototype system for iris recognition (Daugman, 1993). At the coding stage his proposed system establishes a polar coordinate system on the isolated iris image, the origin of the coordinate system being the centre of the circular pupillary boundary. It then defines a plurality of annular analysis bands within the iris image. The portion of the iris image lying within these annular analysis bands is analyzed and encoded employing a special signal processing means comprising a multi-scale, self-similar set of quadrature bandpass filters in polar coordinates, to generate an iris code of fixed length and having a universal format for all irises.

Boles and Boashash (1998) proposed a new algorithm for extracting unique features from images of the iris of the human eye and representing these features using the wavelet transform (WT) zero crossings (Mallat, 1991). A

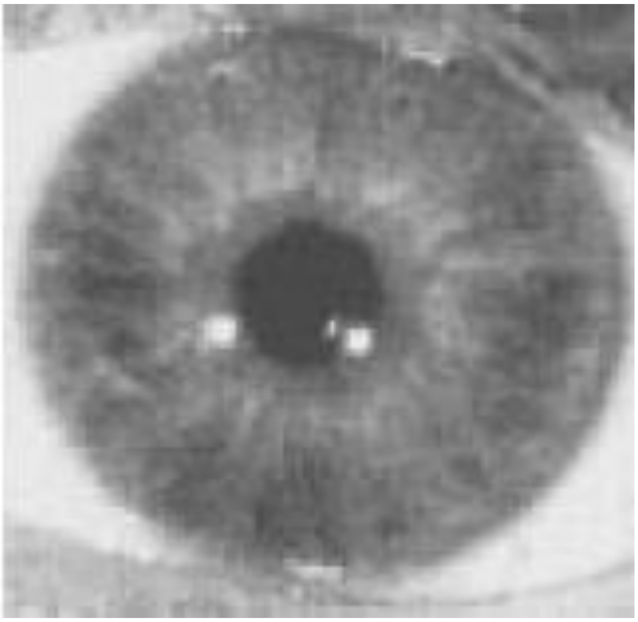

Figure 2. Sample iris image.

wavelet function that is the first derivative of a cubic spline is used to construct the representation. They have only dealt with samples of the grey-level profiles and used these to construct a representation in order to study the characteristics of the irises. Input images are pre-processed to extract the portion containing the iris. Then they proceeded to extract a set of one dimensional (1-D) signals and obtained the zero-crossing representations of these signals. The main idea of the proposed technique is to represent the features of the iris by fine-to-coarse approximations at different resolution levels based on the WT zero-crossing representation. To build the representation, a set of sampled data is collected, followed by constructing the zero-crossing representation based on its dyadic WT. Their process of information extraction starts by locating the pupil of the eye, which can be done using any edge detection technique. Knowing that it has a circular shape, the edges defining it are connected to form a closed contour. The centroid of the detected pupil is chosen as the reference point for extracting the features of the iris. The grey level values on the contours of virtual concentric circles, which are centred at the centroid of the pupil, are recorded and stored in circular buffers. In other words, the dimensions of the irises in the images are scaled to have the same constant diameter regardless of the original size in the images. Furthermore, the extracted information from any of the virtual circles has to be normalized to have the same number of data points. Then a zero-crossing representation is generated from the normalized iris signature.

The dyadic wavelet transform decomposes a signal into a set of signals at different resolution levels. The information at the finer resolution levels is strongly affected by noise. In order to reduce this effect on the zero-crossing representation, only a few low-resolution levels, excluding the coarsest level, were used. Their algorithm is a model-based one in which the original signatures of the different irises to be recognized were represented by their zero-crossing representations. These representations are then stored in the database of the system and are referred to as models. The main task is to match an iris in an image, which is referred to as an unknown, with one of the models whose representations are stored in the database.

The advantage of the method presented in Boles and Boashash (1998) is processing 1-D iris signatures rather than the 2-D images as used in both Daugman (1993) and Wildes et al. (1994). However, their technique has been tested on a small number of real images (with and without noise). Figure 2 shows a sample image and the corresponding extracted data set and its wavelet transform are shown in Figure 3. Figure 4 illustrates the zero-crossing representation of the iris of Figure 2.

Lim et al. (2001) decomposed an iris image into four levels using 2-D Haar wavelet transform and quantized the fourth-level high-frequency information to form an 87-bit code. A modified competitive learning neural network (LVQ) was adopted for classification. Park et al. (2003) used a directional filter bank to decompose an iris image into eight directional subband outputs and extracted the normalized directional energy as features. Bae et al. (2003) projected the iris signals onto a bank of basis vectors derived by independent component analysis and quantized the resulting projection coefficients as features. The global texture features of the iris were extracted by means of well-known Gabor filters at different scales and orientations (Ma et al., 2002a). Based on the experimental results and analysis obtained in Ma et al. (2002a), Ma et al. (2002b) constructed a bank of spatial filters, whose kernels are suitable for iris recognition, to represent the local texture features of the iris and achieved much better results. From the methods described above, it can be concluded that there are four main approaches to iris representation: phase-based methods (Daugman, 2001a, 2003a), zero-crossing representation (Daugman and Downing, 1995; Sanchez-Avila and Sanchez-Reillo, 2002), texture analysis (Lim et al., 2001; Sanchez-Avila and Sanchez-Reillo, 2002; Wildes et al., 1996; Zhu et al., 2000) and intensity variation analysis (Ma et al., 2003).

IRIS RECOGNITION AND IDENTIFICATION

At the registration stage, following iris coding, the identity of each subject can be stored along with the iris code. Next, at the recognition stage, iris codes of queries are compared against the stored iris codes to verify or identify the query. Recognition error rate may increase if the performance at any of the previous stages is degraded. Attempts have been made to improve the

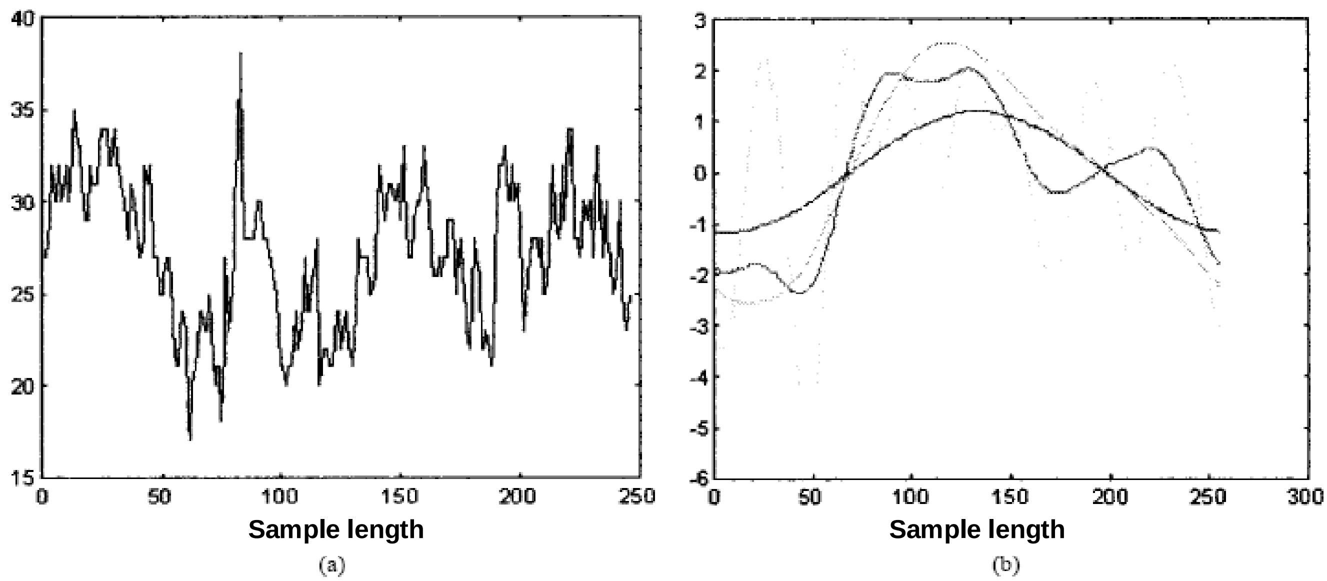

Figure 3. (a) Sample iris signature from the image of Figure 1. (b) Lowest four resolution levels of the wavelet transform.

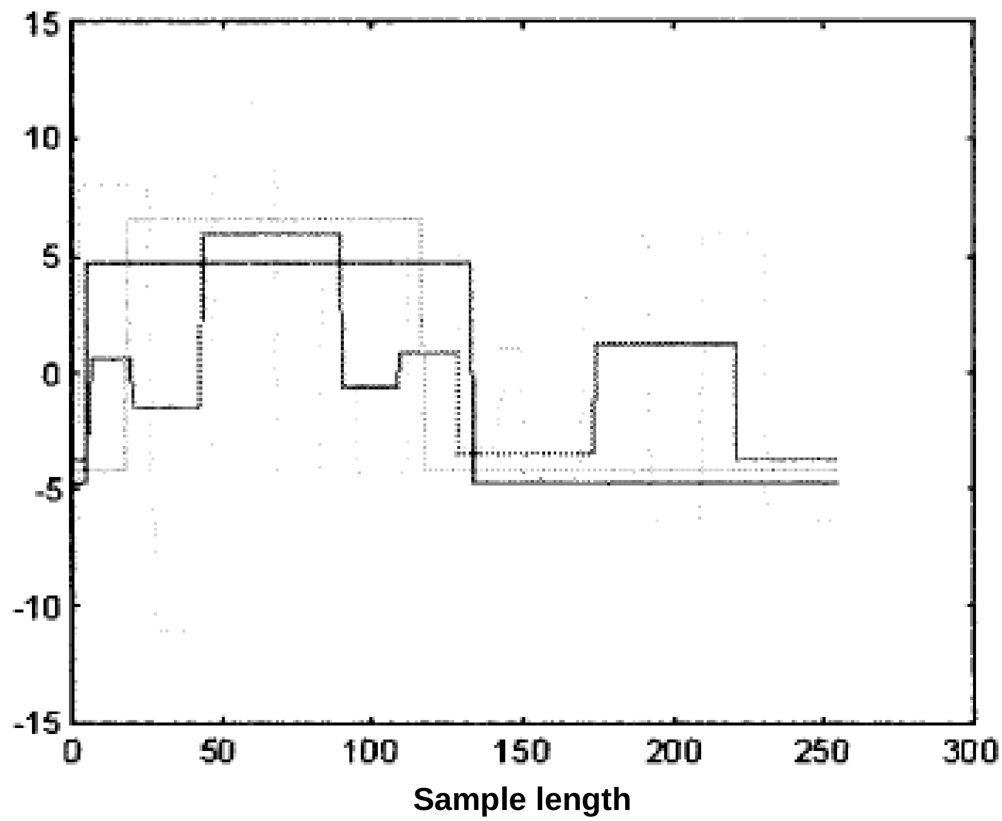

Figure 4. Zero-crossing representation of the iris of Figure 3.

recognition error rate by compensating for these degradations.

For example to deal with off-angle iris, which occurs at the first stage, Abhyankar and Schuckers (2010) propose a bi-orthogonal wavelet network using several neural networks for each angle. Their system recognizes

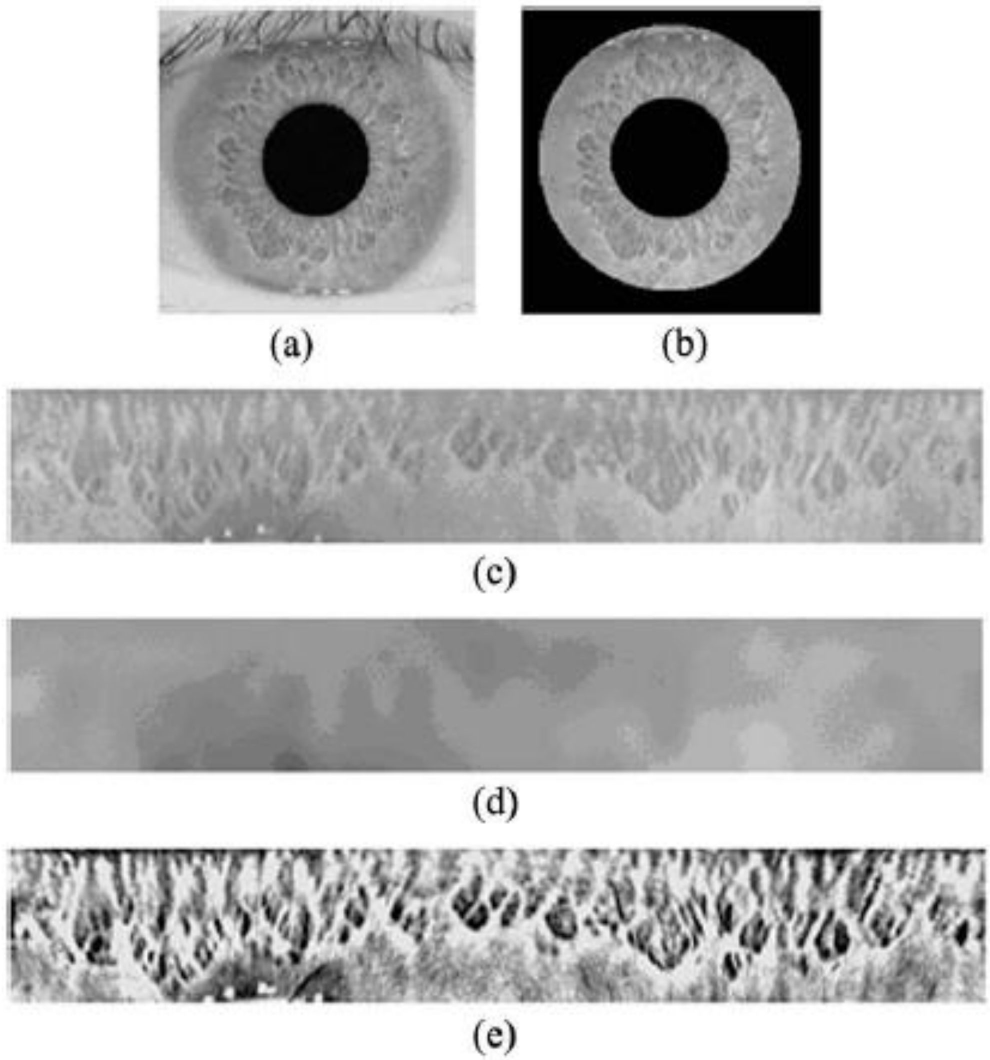

Figure 5. Iris image preprocessing: (a) original image; (b) localized image; (c) normalized image; (d) estimated local average intensity; and (e) enhanced image.

recognizes all classes efficiently up to an angular deformation of less than 45°.

Huang et al. (2002) proposed an iris recognition method which constructs a basis function for the training set using independent component analysis (ICA), represents iris pattern with ICA coefficients, determines the centre of each class by competitive learning mechanism and finally recognizes the pattern based on Euclidian distances. They have shown that their system can work well for lured iris image, variable illumination, and interference of eyelids and eyelashes.

It is possible to repeat the first stage if problems that detrimentally affect the recognition rate are detected at a later stage. Jang et al. (2008) propose a new focus assessment method for iris recognition systems, which combines the wavelet transform method and the Support Vector Machine (SVM). The proposed wavelet-based method, detects omni-directional high-frequency which is the characteristic of iris patterns and estimates focus values by using the ratio of high and low – frequency sub-band averages. The SVM reduces the error rate of the wavelet-based method by finding the optimum threshold.

Kumar et al. (2003) utilized correlation filters to measure the consistency of iris images from the same eye. The correlation filter of each class was designed using the two-dimensional (2-D) Fourier transforms of training images. If the correlation output exhibited a sharp peak, the input image was determined to be from an authorized subject, otherwise an imposter.

A feature correlation evaluation approach is proposed by Du et.al. (2010) to determine iris image quality(Figure 5). This is needed especially for determining the quality of compressed images where artificial patterns are introduced. Their proposed approach can discriminate artificial iris patterns from natural iris patterns in uncompressed images. It can also measure iris image quality of non-compressed and compressed images.

PERFORMANCE ENHANCEMENT

To find which approach is most suitable and to find the advantage of each of the existing recognition systems a comparative analysis must be conducted. Furthermore, to improve the recognition rate of the best available approach, the results of several of the existing systems can be combined. To find which yields the best results, Kumar and Passi (2010) conducted a comparison of different iris recognition methods and experimented with combining the decisions of these approaches. They compare the performance of four different approaches for iris recognition: DCT, FFT, Haar wavelet and Log-Gabor filter. The experimental results suggest that the combination of Log-Gabor and Haar wavelet matching scores using weighted sum rule yield significant improvement over either filter alone. Their approach also uses minimum computational time as they use one training image, in contrast to other methods that use several.

Another analysis to find the effect of different parameters on the recognition rate is conducted in Hollingsworth et al. (2009), where authors consider the effect of dilation on the recognition rate and find a relation between the difference between dilation measures of enrolment and recognition and the recognition rate. They recommend recording the dilation measure for every iris code to be used as a confidence measure.

To answer the question of which approach is most suitable for extracting iris features, Ma et al. (2004) carried out an extensive quantitative comparison among some existing methods and provided detailed discussions on the overall experimental results. They have discussed that the iris consists of many irregular small blocks, such as freckles, coronas, stripes, furrows, crypts, and so on. Furthermore, the distribution of these blocks in the iris is also random. Such randomly distributed and irregular blocks constitute the most distinguishing characteristics of the iris. As such, local sharp variations denote the most important properties of a signal. In their framework, they recorded the position of local sharp variation points as features instead of locating and recognizing those small blocks. The characteristics of the iris can be considered as a sort of transient signals. Local sharp variations are generally used to characterize the important structures of transient signals. Ma et al. (2004) constructed a set of 1-D intensity signals which are capable of retaining most sharp variations in the original iris image. The position of local sharp variation points is recorded as features. A special class of 1-D wavelets has been adopted in their work to represent the resulting 1-D intensity signals: the dyadic wavelets that satisfy such requirements as well as incur lower computational cost. For matching purpose, they have proposed a two-step approach: (1) the original feature vector is expanded into a binary feature vector (called feature transform), (2) the similarity between a pair of expanded feature vectors is calculated using the XOR operation.

CONCLUSION

We have presented an overview of the latest research on iris recognition by categorizing the research in four groups outlined as localization, segmentation, iris coding and recognition. We present the latest developments explaining advances to solve problems associated with image acquisition such as non-frontal face images and off angle iris. We also discuss advances that lead to improvement in iris recognition system performance, improvement in iris coding methods, and improvement in recognition methods. We also present a review on a comparative study of different iris methods to find the effect of different parameters on the recognition rate, and to find an answer to the question of which approach is most suitable for iris recognition.

REFERENCES

Abhyankar A, Schuckers S (2010). A novel biorthogonal wavelet network system for off-angle iris recognition. Pattern recognition. 43(3): 987-1007.

Bae K, Noh S, Kim J (2003). Iris feature extraction using independent component analysis. In Proc. 4th Int. Conf. Audio- and Video-Based Biometric Person Authentication. pp. 838-844.

Boles WW, Boashash B (1998). A Human Identification Technique Using Images of the Iris and Wavelet Transform. IEEE Transaction on Signal Processing, 46(4).

Daugman J (1993). High confidence visual recognition of persons by test of statistical independence. IEEE Trans. Pattern Anal. Machine Intell., 15: 1148-1161.

Daugman J (1994). United States Patent Number: 5291560.

Daugman J, Downing C (1995). Demodulation, predictive coding, and spatial vision. J. Opt. Soc. Am. A 12: 641-660.

Daugman J (2001a). Statistical richness of visual phase information: update on recognizing persons by iris patterns. Int. J. Comput. Vis. 45(1): 25-38.

Daugman J, Downing C (2001b). Epigenetic randomness, complexity and singularity of human iris patterns, Proc. R. Soc. Lond. B 268: 1737-1740.

Daugman J (2003a). Demodulation by complex-valued wavelets for stochastic pattern recognition. Int. J. Wavelets, Multi-Res. and Info. Processing. 1(1): 1-17.

Daugman J (2003b). The importance of being random: statistical principles of iris recognition. Pattern Recognition, 36: 279-291.

Daugman J (2004). How iris recognition works, IEEE trans. On sys. for video tech. 14(1).

Daugman J (2007). New methods in iris recognition", IEEE Trans. On Sys., Man, and Cybernetics-part B. 37(5).

Du Y, Belcher C, Zhou Z, Ives R (2010). Feature correlation evaluation approach for iris feature quality measure. Signal processing, 90(4):1176-1187.

Hanna K, Mandelbaum R, Mishra D, Paragano V, Wixson L (1996). A System for Non-intrusive Human Iris Acquisition and Identification. IAPR Workshop on Machine Vision Applications. pp.12-14.

He Z, Tan T, Sun Z (2010). Topology modeling for Adaboost-cascade based object detection", Pattern recognition letters, 31(9).

Hollingsworth K, Bowyer KW, Flynn PJ (2009). Pupil dilation degrades iris biometric performance. Computer vision and image understanding, 113(1).

Huang Y, Luo S, Chen E (2002). An Efficient Iris Recognition System. Proc. 1st Int'l. Conf. Machine Learning and Cybernetics, China.

Imesh PD, Wallow I, Albert DM (1997). The color of the human eye: a review of morphologic correlates and of some conditions that affect iridial pigmentation, Surv. Ophthalmol., 41(2): 117-123.

Jang J, Park KR, Kim J, Lee Y (2008). New focus assessment method for iris recognition systems. Pattern recognition letters. 29(13).

Jang YK, Kang BJ, Park KR (2008). A study on eyelid localization considering image focus for iris recognition. Pattern recognition letters, 29(11).

Jeong DS, Hwang JW, Kang BJ, Park KR, Won CS, Park DK, Kim J (2010). A new iris segmentation method for non-ideal iris images. Image and vision computing, 28(2): 254-260.

Johnston R (1992). Can iris patterns be used to identify people? Los Alamos National Laboratory, Chemical and Laser Sciences Division Annual Report LA-12331-PR, pp. 81-86.

Kranauskas BJ, Masiulis R (2009). Iris recognition by local extremum points of multiscale Taylor expansion. Pattern recognition. 42(9).

Kronfeld PC (1962) Gross anatomy and embryology of the eye, In: *The eye*, vol. 1 (ed. H. Davson), London: Academic Press.

Kumar A, Passi A (2010). Comparison and combination of iris matchers for reliable personal authentication. Pattern recognition, 43(3): 1016-1026.

Kumar B, Xie C, Thornton J (2003). Iris verification using correlation filters. In Proc. 4th Int. Conf. Audio- and Video-Based Biometric Person Authentication, pp. 697-705.

Labati RD, Scotti F (2010). Noisy iris segmentation with boundary regularization and reflections removal. Image and vision computing, 28(2): 270-277.

Li P, Liu X, Xiao L, Song Q (2010). Robust and accurate iris segmentation in very noisy iris images. Image and vision computing. 28(2).

Lim S, Lee K, Byeon O, Kim T (2001). Efficient iris recognition through improvement of feature vector and classifier. ETRI J. 23(2): 1-70.

Ma L, Wang Y, Tan T (2002a). Iris recognition based on multichannel Gabor filtering," in Proc. 5th Asian Conf. Computer Vision. I: 279-283.

Ma L, Wang Y, Tan T (2002b). Iris recognition using circular symmetric filters," in Proc. 16th Int. Conf. Pattern Recognition. II: 414-417.

Ma L (2003). Personal identification based on iris recognition. Ph.D dissertation, Inst. Automation, Chinese Academy of Sciences, Beijing, China.

Ma L, Tan T, Wang Y, Zhang D (2004). Efficient Iris Recognition by Characterizing Key Local Variations. IEEE Transactions on image processing, 13(6).

Mallat SG (1991). Zero-crossings of a wavelet transform. IEEE Trans. Inform. Theory, 37(14): 1019-1033.

Min TH, Park RH (2009). Eyelid and eyelash detection method in the normalized iris image using the parabolic Hough model and Otsu's thresholding method. Pattern recognition letters. 30(12).

Ng RYF, Tay YH, Mok KM (2008). A review of iris recognition algorithms. International Symposium on Information Technology, Malaysia.

Park C, Lee J, Smith M, Park K (2003). Iris-based personal authentication using a normalized directional energy feature. In Proc. 4th Int. Conf. Audio- and Video-Based Biometric Person Authentication. pp. 224-232.

Perez CA, Aravena CM, Vallejos JI, Estevez PA, Held CM (2010). Face and iris localization using templates designed by particle swarm optimization, Pattern recognition letters, 31(9): 857-868.

Popescu-Bodorin N, Balas VE (2010). AI challenges in iris recognition. Processing tools for Bath iris image database. In Proceedings of the 11th WSEAS international conference on Automation and information.

Proença H, Alexandre LA (2010). Iris recognition: Analysis of the error rates regarding the accuracy of the segmentation stage. Image and vision computing, 28(1): 202-206.

Sanchez-Avila C, Sanchez-Reillo R (2002). Iris-based biometric recognition using dyadic wavelet transform. IEEE Aerosp. Electron. Sys. Mag., 17: 3-6.

Sankowski W, Grabowski K, Napieralska M, Zubert M, Napieralski A (2010). Reliable algorithm for iris segmentation in eye image. Image and vision computing, 28(2).

Sheela SV, Vijaya PA (2010). Iris Recognition Methods - Survey. International Journal of Computer Applications 3(5): 19-25.

Tan T, He Z, Sun Z (2010). Efficient and robust segmentation of noisy iris images for non-cooperative iris recognition. Image and vision computing, 28(2).

Wildes R (1994). A system for automated iris recognition," in Proc. 2nd IEEE Workshop Applicat. Comput. Vision, pp. 121-128.

Wildes R, Asmuth J, Green G, Hsu S, Kolczynski R, Matey J, McBride S (1996). A machine-vision system for iris recognition," Mach. Vis. Applic., 9:1-8.

Wolff E (1948). The anatomy of the eye and orbit, London: H. K. Lewis.

Zhu Y, Tan T, Wang Y (2000). Biometric personal identification based on iris patterns. In Proc. Int. Conf. Pattern Recognition. II: 805-808.

Ziauddin S, Dailey MN (2010). Robust iris verification for key management", Pattern Recognition letters, 31(9).