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A Survey of Biometric Iris Recognition: Security, Techniques and Metrics

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Abstract: Identification of a human is a goal as ancient as humanity itself. As technology and services are evolving in the modern world, human activities and transactions have to proliferate in which rapid and reliable personal identification/authentication is required. The examples include passport control, computer login control, bank automatic teller machines, premises access control and security systems, etc. All such identification efforts share the common goals such as speed, reliability and automation. Biometrics for identification/authentication purposes requires the particular biometric factor is unique for each individual and it can be readily measured and also to be invariant over time. Biometric traits such as signatures, face, iris, fingerprints, voiceprints, retinal and blood vessel patterns can be used. Compared to other traits, human iris on the other hand as an internal organ of the eye well protected from the external environment, easily visible from within 1 m of distance makes it a perfect biometric trait for an identification/authentication system with the ease of speed, reliability and automation.

Key words: Reliability, fingerprints, retinal, voiceprints, biometric trait

INTRODUCTION

With an ever growing emphasis on security systems, automated personal identification based on biometrics has been getting extensive focus in both research and practice over the last decade. The verifier can be identified/authenticated by what he/she knows (password) by what he/she owns (passport) or by whom he/she is (biometrics). Biometrics deals with recognizing a person based on physiological and behavioral characteristics such as face, fingerprints, hand geometry, iris, retinal and vein, etc. Biometric authentication technique based on iris patterns are suitable for high level security systems since, iris recognition is regarded as the most reliable biometrics and has been widely applied in both public and personal security areas. However, users have to highly cooperate with the iris cameras to make his iris images well captured.

Iris is the annular ring between the pupil and the sclera of the eye. The structure of the iris is formed from about 7 months of gestation and remains constant overtime. It exhibits long-term stability and infrequent re-enrolment requirements. The variations in the gray level intensity values distinguish two individuals. The difference exists between identical twins and even between left and right eye of the same person. As the technology is iris pattern-dependent not sight dependent, it can be used by blind people and also iris is highly protected, non-invasive and ideal for handling applications requiring management of large user groups, like voter ID management and also prevents unauthorized access to ATMs, cellular phones, desktop PCs, workstations, buildings and computer networks. The accuracy of iris recognition systems is proven to be much higher compared to other types of biometric systems like fingerprint, handprint and voiceprint (Mir *et al*., 2011). In

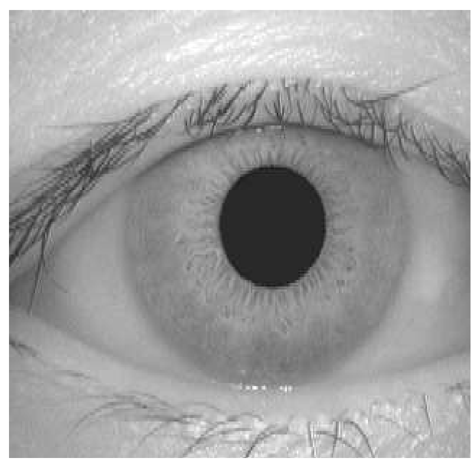

Fig. 1: Normal eye

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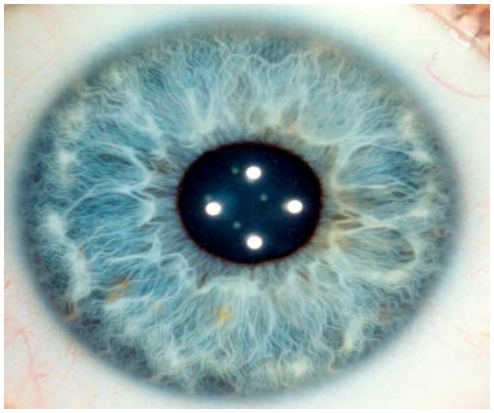

Fig. 2: Iris image

this study, we are going to analyze the steps involved in iris recognition and the techniques used in each step with its features and applications (Fig. 1 and 2).

IRIS RECOGNITION SYSTEM

Iris recognition is a method of biometric authentication that uses pattern-recognition techniques based on high-resolution images of the irises of an individual's eye. The iris are captured via an infrared imaging process which distinguishes the iris from the pupil and sclera portions of the eye. To authenticate via identification (one-to-many template matching) or verification (one-to-one template matching), a template created by imaging the iris is compared to a stored value template in a database. The iris patterns have a wonderful and rich structure and are full of complex textures in contrast to other physiological characteristics. When security is highly desired, iris recognition is a preferred method of identification because the iris patterns are hardly affected by the environment and can hardly be lost. One of the most dangerous security threats is the impersonation in which somebody claims to be somebody else.

Hence, iris biometric authentication can be used to claim the identity of the individual which ensures security (Fig. 3).

A typical iris recognition system has three main stages such as image preprocessing, feature extraction and template matching. The iris image needs to be preprocessed to obtain useful iris region. Before preprocessing iris image is to be captured using a CCD camera with high resolution. Image preprocessing is divided into three steps: iris localization, iris normalization and enhancement. Iris localization detects the inner and outer boundaries of the iris. Iris normalization converts iris image from cartesian coordinates to polar coordinates. The iris image has low contrast and non-uniform

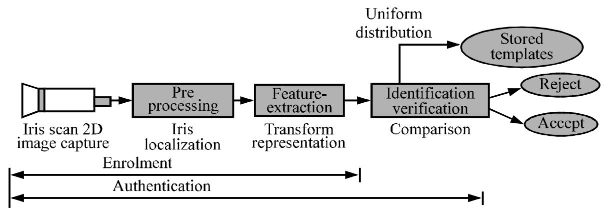

Fig. 3: Iris recognition system

illumination caused by the position of the light source. All these factors can be compensated by the image enhancement algorithms.

In feature extraction significant features of the iris are extracted for the accurate identification purpose. Feature extraction identifies the most prominent features for classification. The features are encoded in a format suitable for recognition. Finally, matching, i.e., authenticates via identification (one-to-many template matching) or verification (one-to-one template matching), a template created by imaging the iris is compared to a stored value template in a database. The matching metric will give a measure of similarity between two iris templates. Finally, a decision of the high confidence level is made to identify whether the user is an authentic or not (Rakesh and Khogare, 2012).

Image acquisition: The iris recognition technology uses camera technology with infrared illumination reducing specular reflection from the convex cornea to create images of the detail rich and intricate structures of the iris. These images are converted into digital templates to provide mathematical representations of the iris that yield unambiguous positive identification of an individual. Image acquisition is considered the most critical step in any iris recognition system since all subsequent stages depend highly on the image quality. In order to accomplish this, a CCD camera is used with the resolution of 640×480, the type of the image to JPEG and the mode to white and black for greater details. Iris image quality evaluation is an especially important step in the automatic iris recognition system, since it avoids the false match and the false non-match caused by bad image quality. The common quality problems for iris image are the eyelid and eyelash occlusion, the blur of the image caused by motion, defocus, distance, sharpness, lighting and resolution (Mei, 2006). An image acquisition consists of illumination, position and physical capture system. The occlusion, lighting, number of pixels on the iris are factors that affect the image quality. Many iris recognition systems require cooperation of the user for image acquisition.

Image preprocessing: Iris image preprocessing is divided into three steps: iris localization, iris normalization and image enhancement. The acquired iris image has to be preprocessed to detect the iris which is an annular portion between the pupil (inner boundary) and the sclera (outer boundary). The first step in iris localization is to detect pupil which is the black circular part surrounded by iris tissues. The center of pupil can be used to detect the outer radius of iris patterns.

Iris localization: The process of localization detects the inner and the outer boundaries of the iris. Both inner and outer iris boundaries can be approximately, modeled as circles. It is not necessary to have the center of the iris and the center of the pupil to be same. In the iris recognition process, localization is considered vital because the exact iris region which is needed to generate the templates for accurate matching is obtained in this phase. Six iris localization algorithms would be discussed in this study. They include integro-differential operator, hough transform, discrete circular active contour, bisection method, black hole search method and eyelid and eyelash detection. An example of preprocessing of an iris image is shown in Fig. 4.

Integro-differential operator: A very effective integro-differential operator proposed by John Daughman is used for locating the inner and outer boundaries of iris as well as the upper and lower eyelids with upper and lower eyelids (Daugman, 1993, 2004). The operator computes the partial derivative of the average intensity of circle points with respect to increasing radius (r). After convolving the operator with Gaussian kernel, the maximum difference between inner and outer circle will define the center and radius of the iris boundary. For upper and lower eyelids detection, the path of contour integration is modified from circular to parabolic curve. The operator is accurate because it searches over the image domain for the global maximum. It can compute

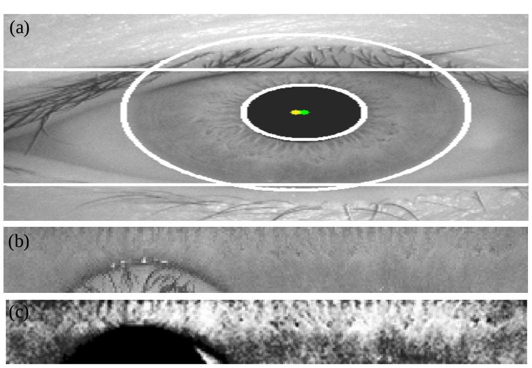

Fig. 4: Iris image preprocessing: a) localized iris image; b) normalized iris image and c) enhanced iris image

faster because it uses the first derivative information with small false acceptance rate and small false rejection rate.

Hough transform: Hough transform is a standard computer vision algorithm used to determine the geometrical parameters in a image such as lines or circles. Since, the inner and outer boundaries of an iris can be modeled as circles, circular Hough transform is used to localize the iris by Wildes (1997), Kong and Zhang (2001), Tisse *et al.* (2002) and Ma *et al.* (2002). Firstly, edge detector is applied to a gray scale iris image to generate the edge map. The edge map is obtained by calculating the first derivative of intensity values and thresholding the results. Gaussian filter is applied to smooth the image to select the proper scale of edge analysis. The voting procedure is realized using hough transform in order to search for the desired contour from the edge map. Assuming a circle with center coordinate (xc, yc) and radius (r), each edge point on the circle casts a vote in hough space. The center coordinate and radius of the circle with maximum number of votes is defined as the contour of interest. For eyelids detection, the contour is defined using parabolic curve parameter instead of the circle parameter. The disadvantage of hough transform algorithm is that it is computationally intensive and therefore not suitable for real time applications. It requires a threshold value to generate the edge map. The selected threshold value may remove some critical edge points and result in false circle detection.

Discrete circular active contour: Active contour model has been used to localize iris by Ritter, Ritter and Cooper. The contour is defined as a set of n vertices connected as a simple closed curve. Active contour respond to internal forces expand the contour into a perfect circle. The external forces push the contour inward across an image until equilibrium is reached. The position of the number of points contained by the contour is changed by two opposing forces. The average radius and centre of contour obtained are the parameters of the iris boundary. The discrete circular active contour search for the iris boundary is affected by the specular reflections from the cornea. Therefore, image preprocessing algorithm is required to remove the specular reflections. The efficiency of active contour model is poor if performed on edge images rather than variance images.

Bisection method: In this method, firstly the edge detection technique is applied to detect the information about edges in the iris image and also to locate the center of the pupil. The center of pupil is considered as reference point to detect the inner and outer boundaries of the iris image. For every two points on the same edge component, a perpendicular line is drawn to the center point. Centre of the pupil is the center point with maximum number of line intersections. A virtual circle is drawn with reference to the center of the pupil and the radius is increased within a certain range. Two virtual circles with the largest number of edge points are chosen as the inner and outer boundaries of the iris. Bisection method is affected by the non-uniform illuminations and glasses reflections (Ali *et al*., 2011; Khan *et al*., 2011). As a result, the iris inner boundary cannot be localized accurately. Similar to the discrete circular active contour method, image preprocessing algorithm is needed to remove the high intensity areas caused by illuminations and reflections.

Black hole search method: Black hole search method is used to compute the center and area of a pupil. Since, the pupil is the darkest region in the image, this approach applies threshold segmentation method to find the region. Firstly, a threshold is defined to identify the dark areas in the iris image. The dark areas are called as "black holes". The center of mass of these black holes is computed from the global image. The area of pupil is the total number of those black holes within the region. The radius of the pupil can be calculated from the circle area formula. Black hole search method is not suitable for iris image with dark iris. The dark iris area would be detected instead of the area of pupil.

Eyelid and eyelash detection: Eyelids and eyelashes may cover the iris region. Eyelids can be detected using texture segmentation and wavelets method. The eyelashes detection algorithms consist of gabor filter, variance of intensity and combination of both edge and region information.

Eyelid detection: Texture segmentation is adopted to detect upper and lower eyelids by Cui *et al.* (2004). The energy of high spectrum at each region is computed to segment the eyelashes. The region with high frequency is considered as the eyelashes area. The information of the pupil position is used in upper eyelashes segmentation. The upper eyelashes are fit with a parabolic arc. The parabolic arc shows the position of the upper eyelid. For lower eyelid detection, the histogram of the original image is used. The lower eyelid area is segmented to compute the edge points of the lower eyelid. The lower eyelid is fit with the edge points. The wavelets method is used to decompose the original image into four bands, HH, HL, LH and LL. Canny edge detection is applied to the LH image. To minimize the influence of eyelashes, canny edge detector is tuned to horizontal direction. The edge points that are close to each other are connected to detect the upper eyelid. The longest connected edge that fits with a parabolic arc is taken as the upper eyelid. To detect lower eyelid, the steps are repeated with lower iris boundary area.

Eyelash detection: Gabor filter and variance of intensity approaches are proposed for eyelash detection. The eyelashes are categorized into separable eyelashes and multiple eyelashes. Separable eyelashes are detected using 1D gabor filters. A low output value is obtained from the convolution of the separable eyelashes with the gabor filter. For multiple eyelashes, the variance of intensity is very small. If the variance of intensity in a window is smaller than a threshold, the center of the window is considered as the eyelashes. According to Huang *et al.* (2004), both the edge and region information are used for noise detection. To speed up iris segmentation, the iris is roughly localized using filtering, edge detection and Hough transform. The localized iris is normalized to rectangular block. A bank of gabor filters is used to extract the edge information based on phase congruency. The obtained edge information is combined with the region information to detect the eyelashes and pupil noise regions.

Iris normalization: After successfully segmenting iris region from an eye image, next step is to transform the iris region to the fixed dimensions. The dimensional inconsistencies between eye images are caused by pupil dilation from varying levels of illumination, varying image distance, rotation and angle of camera and eye. Daugman (1993, 2004) devised the homogeneous rubber sheet model. This model remaps each point within the iris region to polar coordinates from the cartesian coordinates. The resulting deformation of the iris texture will affect the performance of subsequent feature extraction and matching stages. Therefore, the iris region needs to be normalized to compensate for these variations.

Homogenous Rubber Sheet Model: The Homogeneous Rubber Sheet Model algorithm remaps each pixel in the localized iris region from the cartesian coordinates to polar coordinates (Daugman, 1993, 2004). The non-concentric polar representation is normalized to a fixed size rectangular block. The Homogenous Rubber Sheet Model accounts for pupil dilation, imaging distance and non-concentric pupil displacement. However, this algorithm does not compensate for the rotation variance.

Image enhancement: The normalized iris image has low contrast and non-uniform illumination caused by the light source position. The image needs to be enhanced to compensate for these factors. Local histogram analysis is applied to the normalized iris image to reduce the effect of non-uniform illumination and obtain well-distributed texture image. Reflections regions are characterized by high intensity values close to 255. A simple threshold operation can be used to remove the reflection noise (Vatsa *et al*., 2008).

FEATURE EXTRACTION

In this stage, texture analysis methods are used to extract the significant features from the normalized iris image. The extracted features will be encoded to generate a biometric template.

Gabor filters: 2D gabor filters are used to extract iris features in both (Daugman, 1993, 2004). Gabor filter's impulse response is defined by a harmonic function multiplied by a Gaussian function. It provides optimum localization in both spatial and frequency domains. Each pattern is demodulated to extract its phase information using quadrature 2D gabor wavelets. The phase information is quantized into four quadrants in the complex plane. Each quadrant is represented with two bits phase information. Therefore, each pixel in the normalized image is demodulated into two bits code in the template. The phase information is extracted because it provides the significant information within the image. It does not depend on extraneous factors such as imaging contrast, illumination and camera gain. A log gabor filter which is gaussian on a logarithmic scale is proposed by Yao. It has strictly band pass filter to remove the DC components caused by background brightness.

Wavelet transform: Wavelet transform decomposes the iris region into components with different resolutions. The advantage of wavelet transform over Fourier transform is that it has both spatial and frequency resolution which makes it very useful for the feature extraction. It localizes features in both spatial and frequency domain with varying window size. Number of researchers employed the rotated complex wavelet, haar wavelet, biorthogonal, daubechies types of filter banks for the feature extraction. Each filter is tuned for each resolution with each wavelet defined by scaling functions. The output of the filters is encoded to generate a compact biometric template. For the better performance the combination of gabor filter and wavelet filters is employed. A log gabor wavelet filter allows arbitrarily large bandwidth filters to be constructed while still maintaining the zero DC components. The output of the filters is encoded to generate a compact biometric template.

Laplacian of Gaussian filters: Laplacian of Gaussian filters are used to encode feature by decomposing the iris region (Wildes, 1997). The filtered image is realized as a Laplacian pyramid. A cascade of gaussian-like filters is applied to the image. The Laplacian pyramid is constructed with four levels to generate a compact biometric template. This approach compresses the data to obtain significant data. The compressed data can be stored and processed effectively.

Key local variations: Key local variations are used to represent the characteristics of the iris (Ma *et al*., 2004). The normalized iris image is decomposed into a set of 1D intensity signals. Dyadic wavelet transform is applied to each signal. Local extrema of the wavelet transform results correspond to sharp intensity variations of the original signal. The local maximum and minimum points are encoded into a feature vector. The feature vector is converted to a binary template with the same size as the normalized iris image.

Hilbert transform: Hilbert transform is used to extract significant information from iris texture (Tisse *et al*., 2002). Analytic image is constructed by the original image and its Hilbert transform. It can be used to analyze the iris texture. Emergent frequency and instantaneous phase is computed from the analytic image. Emergent frequency is formed by three different dominant frequencies of the analytic image. Instantaneous phase is the arctangent function of the real and imaginary parts of the analytic image. Feature vector is encoded by thresholding the emergent frequency and the instantaneous phase. The advantage of this approach is computationally effective. The filtering is performed in the Fourier domain using pure real filters.

Discrete cosine transform: Iris is coded based on differences of Discrete Cosine Transform (DCT) coefficients of rectangular patches (Monro *et al*., 2007). The normalized image is divided into diagonal 8×12 patches. The average over width is windowed using a Hanning window to reduce the effects of noise. A similar Hanning window and DCT is applied to the patch along its length. The differences between the DCT coefficients of adjacent patches are obtained. A binary template is generated from the zero crossings of the differences between the DCT coefficients. This coding method has low complexity and good interclass separation. It is superior to other approaches in terms of both speed and accuracy.

TEMPLATE MATCHING

The last step in iris recognition system is the matching of individual iris code with that of iris code from the database. The templates generated from the feature extraction stage need a corresponding matching metric. The matching metric compares the similarity between the templates. A threshold is set to differentiate between intra-class and inter-class comparisons.

Hamming distance: Hamming distance is defined as the fractional measure of dissimilarity between two binary templates (Daugman, 1993, 2004). A value of zero would represent a perfect match. The two templates that are completely independent would give a Hamming distance near to 0.5. A threshold is set to decide the two templates are from the same person or different persons. The fractional hamming distance is sum of the exclusive-OR between two templates over the total number of bits. Masking templates are used in the calculation to exclude the noise regions. Only those bits in the templates that correspond to '1' bit in the masking template will be used in the calculation. The advantage of Hamming distance is fast matching speed because the templates are in binary format. The execution time for exclusive-OR comparison of two templates is approximately, 10 μsec (Daugman, 2004). Hamming distance is suitable for comparisons of millions of template in large database.

Weighted Euclidean distance: Weighted Euclidean distance is used to compare two templates to identify an iris (Zhu *et al*., 2000). The templates are composed of integer values. Weighted Euclidean distance is defined as a measure of similarity between two templates. It is calculated using pythagorean theorem to obtain the distance between two points. An iris template is compared with all templates in the database. The two templates are matched if the weighted euclidean distance is a minimum.

Normalized correlation: Normalized correlation between two representations is calculated for goodness of match (Wildes, 1997). It is defined as the normalized similarity of corresponding points in the iris region. The correlations are performed over small blocks of pixels in four different spatial frequency bands. Normalized correlation accounts for local variations in image intensity. However, normalized correlation method is not computationally effective because images are used for comparisons.

Nearest feature line: Nearest feature line is an efficient classification method in template matching stage (Ma *et al*., 2002). Feature line passes through any two feature points of the same class. The feature line extracts more variations of the feature vector than the feature points (Li and Lu, 1999). The distance from a feature point to the feature line is calculated. The nearest feature line distance will be used in the classification stage.

Support vector machine: SVM is an upcoming template matching technique. It is used for pattern matching to verify a person's identity based on the iris code. SVM is a relatively new machine learning technique which is based on the principle of structural risk minimization. A SVM is a binary classifier that optimally separates the two classes. There are two important aspects in the development of SVM as classifier. The first aspect is determination of the optimal hyper plane which will optimally separate the two classes and the other aspect is transformation of non-linearly separable classification problem into linearly separable problem.

PERFORMANCE EVALUATION METRICS

Performance in biometric identification is determined by two kinds of variability among the acquired biometric templates:

- Within-subject variability which sets a minimum false reject rate
- Between-subject variability which sets a minimum false match or false accept rate

Clearly, it is desirable for a biometric to have maximal between-subject variability but minimal within-subject variability. It is also desirable for recognition decisions to be based upon features which have very little genetic penetrance (so that genetically identical or related individuals would still be distinguishable), yet high complexity or randomness and stability over the life of the individual. There are various parameters with the help of which we can measure the performance of any biometric authentication techniques and also the degree of security (Fig. 5):

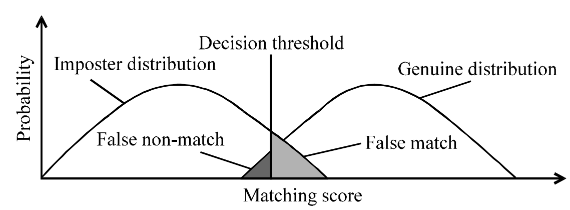

Fig. 5: Performance evaluation graph

- False Accept Rate (FAR) and False Match Rate (MAR): the probability that the system incorrectly declares a successful match between the input pattern and a non-matching pattern in the database. It measures the percent of invalid matches. These systems are critical since, they are commonly used to forbid certain actions by disallowed people
- False Reject Rate (FRR) or False Non-Match Rate (FNMR): the probability that the system incorrectly declares failure of match between the input pattern and the matching template in the database. It measures the percent of valid inputs being rejected
- Relative Operating Characteristic (ROC): in general, the matching algorithm performs a decision using some parameters (e.g., a threshold). In biometric systems the FAR and FRR can typically be traded off against each other by changing those parameters. The ROC plot is obtained by graphing the values of FAR and FRR, changing the variables implicitly
- Equal Error Rate (EER): the rates at which both accept and reject errors are equal. ROC plotting is used because how FAR and FRR can be changed is shown clearly. When quick comparison of two systems is required, the ERR is commonly used. Obtained from the ROC plot by taking the point where FAR and FRR have the same value. The lower the EER, the more accurate the system is considered to be
- Failure to Enroll Rate (FTE or FER): the percentage of data input is considered invalid and fails to input into the system. Failure to enroll happens when the data obtained by the sensor are considered invalid or of poor quality
- Failure to Capture Rate (FTC): within automatic systems, the probability that the system fails to detect a biometric characteristic when presented correctly is generally treated as FTC
- Template capacity: it is defined as the maximum number of sets of data which can be input in to the system

DISCUSSION

An important factor which must be considered for iris recognition system is the effect of noise on its performance. Noisy images are produced due to: gaze (caused due to face expressions), occlusions (caused due to incomplete information), blurring (caused when a moving image is captured), reflections (caused by contact lenses), eyelids and eyelashes. The researches focus on iris localization and their noise removal algorithms are not effective. A complete solution for compensating all types of noises should be implemented to achieve higher accuracy rate. Most researches use the publicly available iris database for experiments. The two most popular iris image databases are CASIA and University of Bath database. These databases have limited number of iris images and the images are captured under controlled condition. Larger database with diversified populations should be used for evaluating the iris recognition algorithms. At the same time iris images under different illumination and angle can also be added to improve the accuracy of iris recognition system. The new developments in the field of using real time iris images can also be considered for improving the quality and accuracy of the iris recognition system.

The major applications of this iris recognition technology so far have been used for substituting passports (automated international border crossing), aviation security and controlling access to restricted areas at airports, database access and computer login, premises access control, hospital setting including mother-infant pairing. In maternity wards, “watch list” screening at border crossings and for biometrically enables national identity cards. Iris recognition is forecast to play a role in a wide range of other applications in which a person’s identity must be established or confirmed which also includes electronic commerce, information security, entitlements authorization, building entry, automobile ignition, forensic and police applications, network access and computer applications or any other transaction in which personal identification currently relies just on special possessions or secrets (keys, cards, documents, passwords, PINs).

CONCLUSION

This study presents a review of the existing algorithms available for the iris recognition. Iris recognition is one of the most accurate and reliable method of human identification in biometric systems. With an ever growing emphasis on security systems, automated personal identification based on biometrics has been getting extensive focus in both research and practical over the last decade. With the increase of smart phone functionalities including personal digital assistance, banking, e-Commerce, remote work, internet access and entertainment, more and more confidential data is stored on these devices. What is protecting this confidential data stored on smart phone and PDA? A large majority of those users believes that an alternative approach to security would be a good idea. Biometric systems are offering a more convenient way to secure private information stored on smart phones. Iris recognition system is a biometric method that has always held the promise of highly accurate identity verification without compromising the issues with mobile devices. With the integration of digital cameras that could acquire iris images at increasingly high resolution and the increase of mobile device computing power, smart phones have evolved into networked personal image capture devices which can perform image processing tasks on the phone itself. Research area is widely open for the researchers to implement iris recognition in the smart phones to secure the personal information and also making an easier use with more user friendliness.

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