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A REVIEW OF IRIS RECOGNITION SYSTEM

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Abstract

Iris recognition system is an accurate biometric system. In recent years, iris recognition is developed to several active areas of research, such as; Image Acquisition, restoration, quality assessment, image compression, segmentation, noise reduction, normalization, feature extraction, iris code matching, searching large database, applications, evaluation, performance under varying condition and multibiometrics. This paper reviews a background of iris recognition and literature of recent proposed methods in different fields of iris recognition system from 2007 to 2015.

Keywords: Iris pattern recognition, iris biometrics, review

Abstrak

Sistem Iris pengiktirafan adalah sistem biometrik tepat. Dalam tahun-tahun kebelakangan ini, pengiktirafan iris dibangunkan ke beberapa kawasan aktif penyelidikan, seperti; Perolehan imej, pemulihan, menilai kualiti, pemampatan imej, segmentasi, pengurangan bunyi, pemulihan, pengekstrakan ciri, kod iris yang hampir sama, mencari pangkalan data yang besar, aplikasi, penilaian, prestasi di bawah pelbagai keadaan dan multibiometrics. Kertas kerja ini mengkaji latar belakang pengiktirafan iris dan kesusasteraan kaedah baru-baru ini dicadangkan dalam pelbagai bidang iris sistem pengiktirafan 2007-2015.

Kata kunci: Corak iris pengiktirafan, iris biometrik, ulasan

1.0 INTRODUCTION

Among all physical biometrics, iris biometric systems are highly secure biometric systems that work at a low false acceptance rate (FAR) [1]. Applications of iris biometrics technology include: identification cards and passports, border control and other government programs, prison security, database access and computer login, schools, aviation security, hospital security, controlling access to restricted areas, entering to buildings and houses [2]. The United Nations High Commissioner for Refugees (UNHCR) used iris recognition for Afghan refugees [3]. Iris recognition is used in jails for the recognition of prisoners. Airports in U.K. United State [4], Canada [5], United Arab Emirates [6], and Singapore, Germany, and the Netherlands all use iris recognition at their boarders and immigration control [7, 8].

Iris biometrics have a number of benefits which are briefly mentioned below:

1. Stability over time — which means that the iris pattern does not change over time compared to other biometrics. Glasses, contact lenses, and even eye surgery does not corrupt the appearance and characteristics of the iris patterns [9-11]. Voice may change by aging or illness; fingerprint may not work for those individuals with no or few minutia points (e.g. this may be the case for surgeons as they often wash their hands with strong detergents, builders, and people with special skin conditions). In addition, finger ridge patterns can be affected by cuts, dirt, or tear. Finally,

the face changes through age, surgery, accidents or make up [12, 13].

2. Ease of collection ― due to the small size of the iris image, a database of iris image of a large population can be saved on a personal computer or a flash memory stick and carried [14-16].

3. Uniqueness ― there is a large inter-class variability, which means large differences between individuals. Among all biometrics, the iris biometric is the most unique and robust biometric – even the iris patterns of twins are different [15, 17, 18].

4. Large number of features ― An iris has more than 200 points, such as rings, furrows, freckles, and the corona [17].

5. Contactless, hygienic [2, 14, 18-20] ― One of the advantages of iris recognition is being contactless. Comparing with fingerprint recognition which it is necessary to touch the finger print device, the iris recognition camera takes the image of eye from distance. In fingerprint biometric system which requires the individual to touch or contact the recognition device, the probability of diseases contagion is high. Due to iris recognition is contactless, the probability of diseases contagion is low, and therefore, iris recognition is known as a hygienic biometric system.

6. High speed and low recognition rate, Capable of 1:N (identification) and 1:1 (verification) matching [15, 21].

The contents of this paper are outlined as follows: section two provides a survey of proposed iris recognition systems, section three reviews the proposed methods in iris segmentation, noise reduction and normalization. Section four presents the literature of feature extraction and encoding and iris code matching. Section five presents a literature of methods in image acquisition, restoration quality assessment and image compression. Section six focuses on iris recognition and multibiometrics. Section seven reviews the proposed iris recognition methods in application and hardware implementation. The last section is devoted to the conclusion.

2.0 IRIS RECOGNITION SYSTEM

From 1992 to 1994, John Daugman proposed a first prototype of an iris recognition system in details [22, 23]. Currently, Daugman's system is used in most commercial iris recognition systems. Daugman's iris system included several stages such as iris segmentation, normalization, feature encoding and iris code matching. In 1994, Wildes *et al*. designed and implemented an automated iris recognition system; he localized iris region using histogram processing, and then filtered the image with the isotropic band pass filters [24]. Later in 1996 Wildes *et al* proposed a machine vision system for iris recognition [25]. In 1997, Wildes proposed an iris recognition system using a diffuse light source [26].

Wildes extracted the boundaries of iris using canny edge detection followed by circular Hough transform function. He produced the templates using Laplacian of Gaussian filter at multiple scale, and in matching stage, he computed the correlation. In 1998, Boles and Boashash proposed an iris recognition system for identification by using iris images and their wavelet transform. They calculated the zero-crossings of wavelet transform for different resolution steps, and then the 1D signals were the result. The matching was obtained by considering two dissimilarity functions between the iris image and iris template [27].

In 2000, Zhu *et al*. presented an iris recognition system for identification mode based on iris patterns and pattern recognition [28]. The system had the global feature extraction, done by applying the multi-channel Gabor filter and wavelet transform. Due to the fact that this system extracted the global features, it was less sensitive to noise. In 2001, El-Bakry *et al*. proposed the fast iris recognition system by using modular neural networks [29]. Lim *et al.* published the system algorithm titled, "Efficient Iris Recognition through Improvement of Feature Vector and Classifier". The segmentation, normalization and feature encoding was the same as the Daugman method. In the matching stage, two learning methods such as a weight vector initialization and the winner selection for learning vector quantization (LVQ) was used to classify the feature vectors. This system covered the identification and verification of individuals [30].

In 2002, Ma L. *et al*. employed circular symmetric filters (CFS) for iris recognition. CFS was a variation of the Gabor wavelet [31]. The Modulation was done by using a circular symmetric sinusoidal function. The boundaries were extracted using edge detection and Hough transform. In this system, it was directed at the fact that center point coordinate of the iris and pupil was usually not the same. Sanchez-Avila *et al*. used dyadic wavelet transform [32]. For classification and verification, they compared the results for Euclidean distance, Hamming distance and the direct distance using zero-crossing, and they concluded that Hamming distance had better results. Also Liam *et al*. obtained an iris recognition system by using self-organizing neural network [33].

In 2003, Ma *et al*. enhanced the method of Wildes and proposed an iris recognition system for personal identification mode [34]. In the iris segmentation stage, before applying edge detection and Hough transform, they estimated the pupil center position. Therefore, the system worked faster and needed less computation processing. They concentrated on two regions in the iris that were not corrupted by eyelash and motion blur and defined a bank of spatial filters for feature extraction.

In 2004, Daugman used a near-infrared camera for acquisition of an iris image [17]. Advantages of this work were that light illumination of environment could be controlled, and patterns of dark irises were visible with details. The iris recognition systems proposed by Daugman [22, 23, 35] and Wildes [36] were designed for both identification and verification mode but the rest were proposed for identification.

Boles and Boashash used 1D signals while Daugman and Wildes worked on 2D images. In Daugman's iris recognition system, the Gaussian filter was used for segmentation. The Gaussian filter has smoothing effect; therefore, this system was sensitive to light illumination and reflections. An argument against system proposed by Wildes is thresholding. Measuring the threshold values make this system very time consuming and therefore computationally expensive [17].

In 2005 Monro, D.M. and Zhang, Z. described a method for reducing the complexity of iris coding and matching. They captured the local frequency variation. They divided the normalized images into rectangular fragments called patches. Then they optimized the performance of system by changing the length, width, angle and position of the patches named patch coding [37]. Later, they used 1D Zero crossings of 1D Discrete Cosine Transform (DCT) [38].

In 2006, Liu and Xie worked on the feature extraction stage. In the second level wavelet decomposition of normalized iris image, they chose only the approximation wavelet coefficients. Then, they applied direct linear discriminant analysis (DLDA). Comparing it with related works such as principle component analysis (PCA) and independent component analysis (ICA), they proved that DLDA method resulted in lower EER [39]. Schuckers *et al*. applied Integro-differential operator and angular deformation model for extracted an iris region. They extracted the features using Independent component Analysis and Biorthogonal wavelets [40].

Table 1 and 2 provide the comparison of algorithms and the evaluations of proposed iris recognition systems.

Table 1 Comparison of iris recognition methods

Method	Iris segmentation	Feature extraction	Matching process
[22, 35]	Integro-differential operator	Binary features vector using 2D Gabor filters.	Hamming distance
[18]	Active contours and generalized coordinates	Iris Code	Hamming distance
[26]	Image intensity gradient and Hough transform	Laplacian pyramid to represent the spatial characteristics of iris image.	Normalized correlation
[41]	Circular iris shape	Zero crossing and 1D signals	Two dissimilarity functions: the learning and the classification
[34]	Gray level information, Canny edge detection and Hough transform	1D real-valued feature vector using multichannel spatial filters with the length of 384	Nearest feature line
[42]	Gray level information, Canny edge detection and Hough transform	1D real-valued feature vector using Dyadic wavelet with the length of 160	Weighted Euclidean distance
[39]	Hough transform	direct linear discriminant analysis (DLDA)	Hamming distance
[40]	Integro-differential operator and angular deformation model	Independent component Analysis and Biorthogonal wavelets	Hamming distance
[37]	Hough transform	Patch coding	Hamming distance
[38]	Hough transform	Zero crossings of 1D Discrete Cosine Transform (DCT)	Hamming distance

Table 2 Comparison of performance evaluations of method

Method	Performance Evaluation
[22, 35]	Good recognition rate and provides a faster iris/pupil detection process on ideal iris images, not working on non-ideal images
[18]	Gaze deviation has been estimated, low time complexity
[26]	Matching process is time consuming. It may be suitable for identification phase not for recognition, not suitable for implementation
[41]	Relatively low recognition rate, faster matching process but high EER, simple 1D feature vector
[34]	Relatively slow feature extraction process
[42]	local features are used for recognition
[39]	Hough transform
[40]	Improved performance on non-ideal dataset
[37]	Relatively lower recognition rate on complex dataset
[38]	Faster feature extraction process, Higher recognition rates and lower EER

3.0 IRIS SEGMENTATION, NOISE REDUCTION AND NORMALIZATION

Iris segmentation is an important stage of iris recognition. Several studies have been proposed in this area. Daugman used active contours for estimating the iris boundaries. He computed the gradient of image in a circular direction. He modeled the eyelid occlusion with separate splines. He used a discrete Fourier series approximation fitted to gradient of the image [18]. Also, Daugman transformed off-angle iris images to frontal image. He defined the parametric equation for the shape of pupil. By applying Fourier series expansions of the proposed equations he determined the gaze direction. Then, he transformed the off-angle image to the frontal image [18].

Ryan *et al*. proposed the starburst method. First they applied smoothing filter and gradient detection filter. They chose the darkest point of the image as a starting point. They computed the image gradient in a circular direction from the starting point. The average of the highest gradients shaped the boundaries of iris region [40]. Pundlik *et al*. presented a labeling method for iris segmentation. They labeled each pixel as either "eyelash" or "non-eyelash". They found intensity variation of each pixel using gradient covariance matrix. They determined a probability of each pixel with neighboring pixels. They used graph-cuts and an alpha beta swap graph-cut to assign eyelash, pupil, iris or background [41].

Schuckers *et al*. presented two approaches to transform an off-angle image into an equivalent frontal image. The first approach was proposed based on pitch and yaw pair. By using the pitch and yaw that shaped maximum radially away from pupil, they transformed the off-angle iris to the frontal image. The second approach was presented based on the relationship between 3-D iris points and 2-D projected points. By obtaining this relationship, the 2-D off-angle image was transformed to the frontal image. The test of the off-angle image had 0 to 30 degrees [39].

Zhou *et al*. improved Daugman's algorithm in order to locate the iris boundaries using an improved snake model and vector field convolution (VFC); one result of this method was that the inner boundary of iris was more accurate [42]. Moghadam *et al*. reduced the localization error by applying feedforward neural network (FFNN). They reduced neural network errors by designing one neural network for each output neuron and applying a cascaded feedforward neural network (CFFNN) [43].

Li and Savvides detected valid and invalid iris regions based on probabilistic distributions of the extracted Gabor features using Gaussian mixture models [44]. Later they estimated iris occlusion based on a high-dimensional density estimation [45]. Tan and Kumar found Zernike moments around pixels and classified the iris and non-iris regions using SVM classifiers. They extracted iris boundaries using parametric curves [46]. Karakaya *et al*. improved the edge detection method for off-angle iris images. First, they applied canny edge detector in order to collect edges from the iris boundaries, which also collected eyelash, eyelids, and iris texture edges. They classified the edges points and randomly generated subsets of iris and pupil edge points. They fitted ellipses with similar parameters for each subset of the edge points by using the least square ellipse fitting method [47]. Radman *et al*. proposed eyelid detection in order to improve iris segmentation. They utilized live-wire technique to detect eyelid boundaries by using the intersection points between the eyelid and outer iris boundaries. Since live-wire technique is sensitive to noise, a noise reduction procedure should be applied before iris segmentation [48].

Uhl and Wild improved the speed of traditional Hough transforms by applying weighted adaptive Hough transforms in order to locate the center of concentric circular boundaries based on gradient magnitude and orientation [49]. Tang and Weng applied a SVM classifier in order to detect limbic boundary using gradient and shape features [50]. Li *et al*. classified boundary detection into left/right pupillary boundary and left/right limbic boundary detection. They learned the class-specific boundary detectors by applying Adaboost [50].

Yadav *et al*. detected some obstacles such as textures-contact lenses which completely occlude whole iris region [51]. If the iris image is completely occluded, the image is disqualified for iris recognition. Also, the quality of an iris image can be degraded by the motion of the eye. This type of image is called motion-blurred iris image [52]. Nigam classified iris image based on the quality of image [53].Some methods have been proposed for degraded images and compression [54, 55]. Dehkordi and Abu-Bakar detected noise region using multiple thresholding and filled the noise pixels with the iris pattern region's average value [56]. Later they proposed an adaptive fuzzy switching filter (AFSNR) for iris noise reduction [97].

Karn *et al*. proposed a method to reject disqualified images. They decomposed the image into a sparse error matrix and the low-rank matrix. They determined an index to validate the iris recognition. If the determined index exceeded the threshold value, the system rejects the image [58]. Bazama and Hassan proposed a hybrid filter consisting of the cellular automata (CA) filter and standard median filter [59]. Joshi *et al*. proposed an eyelid detection method based on least square and curve fitting model [60]. Si *et al*. used directional filter to classify and detect the eyelash texture [61].

4.0 FEATURE EXTRACTION, FEATURE ENCODING AND MATCHING

Miyazawa *et al*. proposed an algorithm with fewer parameters compared to Daugman's method. They extracted the unoccluded iris region in template image and enrolled image. Then they applied the discrete Fourier Transform followed by Phase Only Correlation function (POC). Using the POD function, they compared the phase component of both unoccluded regions. They filtered high-frequency noise by using band-limited POC. Two parameters in their proposed method gave the effective horizontal bandwidth and the effective vertical bandwidth [96]. Bodade and Talbar used 2D Dual Trace Complex Wavelet Transform (CWT). Compared to Discrete Wavelet transform (DWT), 2D Dual Trace Rotated CWT extracted more features and provided shift invariance [64]. Some works presented methods for the improvement of iris code matching. Ring and Bowyer removed the local texture distortion. They avoided match comparisons within a local window with high fractional Hamming distance [65].

In another approach, Hollingsworth *et al*. masked fragile bits having complex coefficient with real part close to 0. Also, if the imaginary part of complex coefficient was close to 0, they masked that bit. The threshold value for masking was 25% of complex numbers closest to 0 [66]. Barzegar *et al*. reported that for applying method proposed by [66] to the CASIA V3.0 threshold of 35% gave the best results [67]. Dozer *et al*. masked trained fragile bits. For creating a mask of fragile bits for each subject, they trained a set of 10 images [68, 69]. Thainimit *et al*. introduced the physiology of iris and described the problem of iris surface deformation and normalization. They emphasized that an in-depth investigation on iris surface deformation would result in more reliable iris recognition [70].

To extract the features of low quality image in uncontrolled conditions several iris texture representations have been introduced. Lin *et al*. proposed a hybrid texture representation method consisting of conformal geometric algebra (CGA) and Markov random field (MRF) [71]. Da Costa and Gonzaga [72] concentrated on dynamic features in order to collect the properties of iris images under NIR and visible-light illuminations, whereas Zhang *et al*. used advanced image-based correlation and global features [73].

Zhang *et al*. fused the band-pass geometric features and low-pass ordinal features to solve the problem of pupillary deformation [74]. Zhang *et al*. used Daisy features and key-point selection for matching the deformed iris pattern [75]. Xiao *et al*. used the coupled feature selection method for cross-sensor iris recognition. They solved the formulation using l21 regularization and a half quadratic optimization [76]. Pillai *et al*. applied a kernel learning method for sensor adaption. As a result of this method, the intra-class distance was reduced and inter-class distance of cross-sensor comparisons was increased [77]. Omelina *et al*. proposed a feature extraction method based on optimized convolution kernels with a simulated annealing algorithm [78].

5.0 ACQUISITION, RESTORATION, QUALITY ASSESSMENT AND IMAGE COMPRESSION

He *et al*. presented a cheap cost camera for iris recognition. They chose CCD camera because CCD cameras are cheaper than CMOS commercial cameras, while these CCD cameras capture iris image with good quality. The proposed camera has a CCD sensor with resolution of 0.48 million pixels, fixed focus lens at 250 mm and 700 and 900 nm NIR-pass filters [19].

Kang and Park presented a method to restore blurry iris images in real time. They estimated the parameters of PSF based on information of camera optics. Based on these parameters, they restored the probe image. The proposed system had 0.37% equal error rate (EER). The operable depth of camera was increased from 22 mm to 50 mm [79].

Kalka *et al*. used different factors in quality metric for the iris image. They used present occlusion, defocus, gaze deviation, and amount of light reflection. The test of defocus was on bottom half of eye. They estimated the gaze direction using circularity of the pupil. They rotated the off-angle image using projective transformation. Kalka *et al*. demonstrated that the ICE data base contains more defocused images, while the CASIA data base contains more occluded images and WVU database contains more lighting variation than other databases [80]. Zhang *et al*. extended the depth of field of an iris imaging system using light field cameras [81].

6.0 MULTIBIOMETRICS

Lin *et al*. applied a posterior union model (PUM) to provide face- iris multibiometrics. The XM2VTS or AR face database and CASIA iris database were used in this work. They divided the normalized face image into 16 regions and the iris region into 4 parts [82]. Gan and Liu proposed a method based on a discrete wavelet transform and a kernel Fisher discriminant analysis using ORL face database and CASIA V1 iris database [83]. Wang *et al*. presented iris-face fusion method at the feature level using complex feature vector of iris and face feature vectors. Then, they applied complex Fisher discriminate analysis to increase the between-class scatter using CASIA V1 iris database and ORL and Yale face databases [84]. Kim *et al*. implemented a multimodal biometric system based on face and both irises fusion using a support vector machine [85].

7.0 APPLICATION AND HARDWARE IMPLEMENTATION

Garg *et al*. used iris recognition to identify the people who use hand gestures control devices [86]. Leonard *et al*. provided fingerprint, iris, retina, and DNA ("FIRD") recognition to identify patients [87]. Wang *et al*. proposed an application to recognize the large animals from the farm to the slaughterhouse for food chain safety using Daugman's method [88]. Dutta *et al*. proposed a watermarking method; they embedded an iris code in an audio file as identity of ownership of the audio file [89, 90]. Liu-Jimenez *et al*. [91] implemented iris biometric algorithms on FPGAs. Vandal and Savvides used parallelized iris matching for processing on graphics processing units of state-of-the-art single-core CPUs and as results the system was 14 times faster [92].

Kim and Youn developed a smartphone-based pupillometer, a device to measure the diameter of the pupil of the eye. They used both white and infrared LEDs and a 3M pixel camera [93]. Sun *et al*. presented a literature review of three kinds of applications, i.e. iris aliveness detection, human race classification and coarse iris classification [94]. McCloskey *et al*. used a fluttering shutter technique to solve problem of motion blur [95].

8.0 CONCLUSION

This paper provides literature review of iris in several active areas of research, such as; image acquisition, restoration, quality assessment, image compression, segmentation, noise reduction, normalization, feature extraction, feature encoding, iris code matching, searching large database, applications, evaluation, performance under varying condition and multibiometrics. Iris recognition is a reliable biometric system and currently it is used in several real time user applications such as ATM machines, prisoner authentication, banking, border controls, and airport.

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References

[1] Wayman, J. 2014. *Handbook of Iris Recognition*. Biometrics, IET. 3: 41-43.
[2] Daugman, J. 2009. Iris Recognition at Airports and Border-Crossings. *Encyclopedia of Biometrics.* ed: Springer. 819-825.
[3] 2003. Iris Testing of Returning Afghans Passes 200,000 Mark. Available: http://www.unhcr.org/cgi-bin/texis/vtx/search?docid=3f86b4784.
[4] US-VISIT Biometric Identification Services. Available: http://www.dhs.gov/xprevprot/programs/gc-1208531081211.shtm.
[5] Canadian Border Services Agency, CANPASS Available: http://cbsa-asfc.gc.ca/publications/pub/bsf5017-eng.html.
[6] United Arab Emirates deployment of iris recognition. Available: http://www.cl.cam.ac.uk/jgd1000/deployments.html.
[7] Iris scans at Amsterdam Airport Schiphol. Available: http://www.schiphol.nl/Travellers/AtSchiphol/Privium/Privium/IrisScans.htm.
[8] Daugman, J. *Iris Recognition at Airports and Border-Crossings*. Computer Laboratory University of Cambridge, Cambridge. UK.
[9] Browning, K. and Orlans, N. 2014. *Biometric Aging.*
[10] Daugman, J. and Downing, C. 2013. No Change Over Time is Shown in Rankin *et al*. Iris Recognition Failure Over Time: The Effects Of Texture. *Pattern Recognition*. 46: 609-610.
[11] Fenker, S. P., Ortiz, E. and Bowyer, K. W. 2013. Template Aging Phenomenon in Iris Recognition. *Access, IEEE*. 1: 266-274.
[12] Jain, A. K., Flynn, P. J. and Ross, A. A. 2008. *Handbook of Biometrics*. Springer.
[13] Ross, A. A., Ross, K. Nandakumar, and Jain, A. K. 2006. *Handbook of Multibiometrics*. Springer. 6.
[14] CASIA V.3 Iris Image Database Version Three. Available: http://www.cbsr.ia.ac.cn.
[15] Daugman, J. 2006. Probing the Uniqueness and Randomness of Iris Codes: Results from 200 Billion Iris Pair Comparisons. *Proceedings of the IEEE*. 94: 1927-1935.
[16] Quinn, G., Grother, P. and Tabassi, E. 2013. Standard Iris Storage Formats. *Handbook of Iris Recognition.* Springer. 55-66.
[17] Daugman, J. 2004. How Iris Recognition Works. *Circuits and Systems for Video Technology, IEEE Transactions on*. 14: 21-30.
[18] Daugman, J. 2007. New Methods in Iris Recognition. *Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on*. 37: 1167-1175.
[19] He, X., Yan, J., Chen, G. and Shi, P. 2008. Contactless Autofeedback Iris Capture Design. *Instrumentation and Measurement, IEEE Transactions on.* 57: 1369-1375.
[20] iCAM7000 series. Available: http://www.irisid.com/icam7000series.
[21] Némesin, V. and Derrode, S. 2014. Quality-driven and Real-Time Iris Recognition from Close-Up Eye Videos. *Signal, Image and Video Processing*. 1-8.
[22] Daugman, J. G. 1993. High Confidence Visual Recognition of Persons by a Test of Statistical Independence. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*. 15: 1148-1161.
[23] Daugman, J. 1994. Biometric Personal Identification System Based on Iris Analysis. *Google Patents*.
[24] Wildes, R. P. A., Green, G. L., Hsu, S. C., Kolczynski, R. J., Matey, J. R., and McBride, S. E. 1994. A System for Automated Iris Recognition. *IEEE. Workshop on Applications of Computer Vision*. 121-128.
[25] Wildes, R. P. A., Green, G. L., Hsu, S. C., Kolczynski, R. J., Matey, J. R., and McBride, S. E. 1996. A Machine Vision System for Iris Recognition. *Machine Visual and Application.* 9: 1-8.
[26] Wildes, R. P. 1997. Iris Recognition: An Emerging Biometric Technology. *Proceedings of the IEEE*. 85: 1348-1363.
[27] Boles, W. W. B. B. 1998. A Human Identification Technique Using Images of the Iris and Wavelet Transform. *IEEE Transactions on Signal Processing*. 46: 1185-1188.
[28] Zhu, Y., Tan, T., and Wang, Y. 2000. Biometric Personal Identification Based on Iris Patterns. *Pattern Recognition, International Conference on*. 2801-2801.
[29] El-Bakry, H. M. 2001. Fast Iris Detection for Personal Identification Using Modular Neural Networks. *IEEE International Symposium on Circuits and Systems*. 581-584.
[30] Lim, S., Lee, K., Byeon, O., and T. Kim. 2001. Efficient Iris Recognition Through Improvement of Feature Vector and Classifier. *ETRI Journal*. 23: 61-70.
[31] Ma, L., Wang, Y., and Tan, T. 2002. Iris Recognition Using Circular Symmetric Filters. *16th International Conference on Pattern Recognition*. 414-417.
[32] Sanchez-Avila, C., Sanchez-Reillo, R., and de Martin-Roche, D. 2002. Iris-based Biometric Recognition Using Dyadic Wavelet Transform. *IEEE Aerospace and Electronic Systems Magazine*. 17: 3-6.
[33] Liam, L. W., Chekima, A., Fan, L. C., and Dargham, J. A. 2002. Iris Recognition Using Self-organizing Neural Network. *Research and Development Student Conference SCOReD*. 169-172.
[34] Ma, L., Tan, T., Wang, Y., and Zhang, D. 2003. Personal Identification Based on Iris Texture Analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 25: 1519-1533.
[35] Daugman, J. 1993. High Confidence Visual Recognition of Persons by a Test of Statistical Independence. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 15: 1148-1161.
[36] Daugman, J. 1994. Biometric Personal Identification System Based on Iris Analysis. *Google Patents*.
[37] Daugman, J. 2003. The Importance of Being Random: Statistical Principles of Iris Recognition. *Pattern Recognition*. 36: 279-291.
[38] Wildes, R. P., Asmuth, J. C., Green, G. L., Hsu, S. C., Kolczynski, R. J., and Matey, J. R. 1996. A Machine-vision System for Iris Recognition. *Machine Vision and Applications.* 9: 1-8.
[39] Monro, D. M. and Zhang, D. 2005. An Effective Human Iris Code with Low Complexity. *IEEE International Conference on Image Processing*. 3: 277-80.
[40] Monro, D. M., Rakshit, S., and Zhang, D. 2007. DCT-Based Iris Recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 29: 586-595.

[41] Liu, C. and Xie, M. 2006. Iris Recognition Based on DLDA. *18th International Conference on Pattern Recognition*. 489-492.

[42] Schuckers, S. A., Schmid, N. A., Abhyankar, A., Dorairaj, V., Boyce, C. K., and Hornak, L. A. 2007. On Techniques for Angle Compensation in Nonideal Iris Recognition. *IEEE Transactions on Systems, Man, and Cybernetics, Cybernetics*. (B)37: 1176-1190.

[43] Ryan, W. J., Woodard, D. L., Duchowski, A. T., and Birchfield, S. T. 2008. Adapting Starburst for Elliptical Iris Segmentation. *2nd IEEE International Conference on Biometrics: Theory, Applications and Systems*. 1-7.

[44] Pundlik, S. J., Woodard D. L., and Birchfield, S. T. 2008. Non-Ideal Iris Segmentation Using Graph Cuts. *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops.* 1-6.

[45] Zhou, S. and Sun, J. 2013. A Novel Approach for Code Match in Iris Recognition. *IEEE/ACIS 12th International Conference on Computer and Information Science (ICIS)*. 123-128.

[46] Moghadam, F. M., Ahmadi, A. and Keynia, F. 2013. A New Iris Detection Method based on Cascaded Neural Network. *Journal of Computer Sciences and Applications*. 1: 80-84.

[47] Li, Y.-h., and Savvides, M. 2009. Fast and Robust Probabilistic Inference of Iris Mask. *Proceedings of SPIE*. 7306: 730621.

[48] Li, Y.-h., Marios, S. 2013. An Automatic Iris Occlusion Estimation Method Based on High-dimensional Density Estimation. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 35: 784-796.

[49] Tan, C.-W. and Kumar, A. 2012. Unified Framework for Automated Iris Segmentation Using Distantly Acquired Face Images. *IEEE Transactions on Image Processing.* 21: 4068-4079.

[50] Karakaya, M., Barstow, D., Santos-Villalobos, H., and Boehnen, C. 2013. An Iris Segmentation Algorithm based on Edge Orientation for Off-Angle Iris Recognition. *IS&T/SPIE Electronic Imaging*. 866108-866108.

[51] Radman, A., Zainal, N., and Ismail, M. 2013. Efficient Iris Segmentation based on Eyelid Detection. *Journal of Engineering Science and Technology*. 8: 399-405.

[52] Uhl, A. and Wild, P. 2012. Weighted Adaptive Hough And Ellipsopolar Transforms for Real-time Iris Segmentation. *5th IAPR International Conference on Biometrics (ICB)*. 283-290.

[53] Tang, R. and Weng, S. 2011. Improving Iris Segmentation Performance via Borders Recognition. *International Conference on Intelligent Computation Technology and Automation (ICICTA).* 580-583.

[54] Yadav, D., Kohli, N., Doyle, Singh, J. R., Vatsa, M., and Bowyer, K. W. 2014. *Unraveling the Effect of Textured Contact Lenses on Iris Recognition.*

[55] Shukri, M., Asmuni, H., Othman, R. M., and Hassan, R. 2013. An Improved Multiscale Retinex Algorithm for Motion-Blurred Iris Images to Minimize the Intra-individual Variations. *Pattern Recognition Letters*. 34: 1071-1077.

[56] Nigam, A., Anvesh, T., and Gupta, P. 2013. Iris Classification Based on Its Quality. *Intelligent Computing Theories. Springer*: 443-452.

[57] Othman, N., Houmani, N., and Dorizzi, B. 2015. Quality-Based Super Resolution for Degraded Iris Recognition. *Pattern Recognition Applications and Methods*. Springer. 285-300.

[58] Rathgeb, C. and Busch, C. 2013. Comparison Score Fusion Towards an Optimal Alignment for Enhancing Cancelable Iris Biometrics. *Fourth International Conference on Emerging Security Technologies (EST).* 51-54.

[59] Dehkordi, A. B., and Abu-Bakar, S. A. 2013. Noise Reduction in Iris Recognition Using Multiple Thresholding. *IEEE International Conference on Signal and Image Processing Applications (ICSIPA)*. 140-144.

[60] Karn, P., He, X. H., Yang, S., and Wu, X. H. 2014. Iris Recognition Based on Robust Principal Component Analysis. *Journal of Electronic Imaging*. 23: 063002-063002.

[61] Bazama, A. E., and Hassan, Y. F. 2012. Hybrid System of Cellular Automata, PCA and Support Vector Machine for Noise Reduction and Classification in Human Iris Recognition. *IJIIP: International Journal of Intelligent Information Processing*. 3: 47-67.

[62] Joshi, N., Shah, C., and Kaul, K. 2012. A novel approach implementation of eyelid detection in biometric applications. *Nirma University International Conference on Engineering (NUiCONE).*1-6.

[63] Si, Y., Mei, J., and Gao, H. 2012. Novel approaches to improve robustness, accuracy and rapidity of iris recognition systems. *IEEE Transactions on Industrial Informatics.* 8:110-117.

[64] Bodade, R. M., and Talbar, S. N. 2009. Shift invariant iris feature extraction using rotated complex wavelet and complex wavelet for iris recognition system. *Seventh International Conference on Advances in Pattern Recognition*. 449-452.

[65] Ring, S. and Bowyer, K. W. 2008. Detection of iris texture distortions by analyzing iris code matching results. *2nd IEEE International Conference on Biometrics: Theory, Applications and Systems (BTAS).* 1-6.

[66] Hollingsworth, K. P., Bowyer, K. W. and Flynn, P. J. 2009. Using fragile bit coincidence to improve iris recognition. *IEEE 3rd International Conference on Biometrics: Theory, Applications, and Systems (BTAS'09).*1-6.

[67] N. Barzegar and M. S. Moin. 2009. A New User Dependent Iris Recognition System Based on an Area Preserving Pointwise Level Set Segmentation Approach. *EURASIP Journal on Advances in Signal Processing*. 1- 5.

[68] Dozier, G., Bell, D., Barnes, L., and Bryant, K. 2009. Refining Iris Templates via Weighted Bit Consistency. *Proc. Midwest Artificial Intelligence and Cognitive Science (MAICS) Conference*. 1-5.

[69] Dozier, G., Frederiksen, K., Meeks, R., Savvides, M., Bryant, K., Hopes, D. 2009. Minimizing the Number Of Bits Needed for Iris Recognition via Bit Inconsistency and Grit. *IEEE Workshop on Computational Intelligence in Biometrics: Theory, Algorithms, and Applications (CIB 2009)*. 30-37.

[70] Thainimit, S., Alexandre, L. A., and de Almeida, V. 2013. Iris Surface Deformation and Normalization. *13th International Symposium on Communications and Information Technologies (ISCIT).* 501-506.

[71] Lin, M., Ying, H., Haifeng, L., Naimin, L., and Zhang, D. 2014. A CGA-MRF Hybrid Method for Iris Texture Analysis and Modeling. *International Conference on Medical Biometrics (ICMB)*. 1-6.

[72] da Costa, R. M., and Gonzaga, A. 2012. Dynamic Features for Iris Recognition. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics.* 42: 1072-1082.

[73] Zhang, M., Sun, Z., and Tan, T. 2012. Perturbation-enhanced Feature Correlation Filter for Robust Iris Recognition. *Biometrics, IET*. 1: 37-45.

[74] Zhang, M., Sun, Z., and Tan, T. 2013. Deformed Iris Recognition Using Bandpass Geometric Features and Lowpass Ordinal Features. *International Conference on Biometrics (ICB)*. 1-6.

[75] Zhang, M., Sun, Z., and Tan, T. 2011. Deformable Daisy Matcher for Robust Iris Recognition. *18th IEEE International Conference on Image Processing (ICIP)*. 3189-3192.

[76] Xiao, L., Sun, Z., He, R., and Tan, T. 2013. Coupled Feature Selection for Cross-Sensor Iris Recognition. *IEEE Sixth International Conference on Biometrics: Theory, Applications and Systems (BTAS).* 1-6.

[77] Pillai, J. K., Puertas, M., and Chellappa, R. 2014. Cross-sensor Iris Recognition Through Kernel Learning. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 36: 73-85.

[78] Omelina, L., Jansen, B., Oravec, M. and Cornelis, J. 2013. Feature Extraction for Iris Recognition Based on Optimized Convolution Kernels. *Image Analysis and Processing–ICIAP Springer*. 141-150.

[79] Kang, B. J. and Park, K. R. 2007. Real-time Image Restoration for Iris Recognition Systems. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*. 37: 1555-1566.

[80] Kalka, N. D., Zuo, J., Schmid, N. A., and Cukic, B. 2010. Estimating and Fusing Quality Factors for Iris Biometric Images. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans*. 40: 509-524.

[81] Zhang, C., Hou, G., Sun, Z., Tan, T., and Zhou, Z. 2013. Light Field Photography for Iris Image Acquisition. *Biometric Recognition*. Springer. 345-352.

[82] Lin, J., Li, J.-P., Lin, H., and Ming, J. 2009. Robust Person Identification with Face and Iris by Modified PUM Method. *International Conference on Apperceiving Computing and Intelligence Analysis (ICACIA)*. 321-324.

[83] Gan, J.-Y. and Liu, J.-F. 2009. Fusion and Recognition Of Face and Iris Feature Based on Wavelet Feature and KFDA. *International Conference on Wavelet Analysis and Pattern Recognition (ICWAPR)*. 47-50.

[84] Wang, Z., Li, Q., Niu, X., and Busch, C. 2009. Multimodal Biometric Recognition based on Complex KFDA. *Fifth International Conference on Information Assurance and Security (IAS'09)*. 177-180.

[85] Kim, Y. G., Shin, K. Y., Lee, E. C., and Park, K. R. 2012. Multimodal Biometric System Based on the Recognition of Face and Both Irises. *Int J Adv Robotic Sy*. 9.

[86] Garg, R., Shriram, N., Gupta, V., and Agrawal, V. 2009. A Biometric Security Based Electronic Gadget Control Using Hand Gestures. International Conference on Ultra Modern Telecommunications & Workshops (ICUMT'09).1-8.

[87] Leonard, D., Pons, A. P., and Asfour, S. S. 2009. Realization of a Universal Patient Identifier for Electronic Medical Records Through Biometric Technology. *IEEE Transactions on Information Technology in Biomedicine*. 13: 494-500.

[88] Wang, X., Zhao, L., and Kong, Q. 2009. Iris Recognition System Design and Development of Large Animals for Tracing Source of Infection. *International Joint Conference on Computational Sciences and Optimization (CSO)*. 610-613.

[89] Dutta, M. K., Gupta, P., and Pathak, V. K. 2009. Biometric Based Unique Key Generation for Authentic Audio Watermarking. *Pattern Recognition and Machine Intelligence*. Springer. 458-463.

[90] Dutta, M. K., Gupta, P., and Pathak, V. K. 2009. Biometric Based Watermarking in Audio Signals. *International Conference on Multimedia Information Networking and Security (MINES'09)*. 10-14.

[91] Liu-Jimenez, J., Sanchez-Reillo, R., and Fernandez-Saavedra, B. 2011. Iris Biometrics for Embedded Systems. *IEEE Transactions on Very Large Scale Integration (VLSI) Systems.* 19: 274-282.

[92] Vandal, N. A. and Savvides, M. 2010. CUDA Accelerated Iris Template Matching on Graphics Processing Units (GPUs). *Fourth IEEE International Conference on Biometrics: Theory Applications and Systems (BTAS).* 1-7.

[93] Kim, T.-H. and Youn, J.-I. 2013. Development of a Smartphone-based Pupillometer. *Journal of the Optical Society of Korea*. 17: 249-254.

[94] Sun, Z., Zhang, H., Tan, T., and Wang, J. 2014. Iris Image Classification Based on Hierarchical Visual Codebook. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 36: 1120-1133.

[95] McCloskey, S., Au, W., and Jelinek, J. 2010. Iris Capture from Moving Subjects Using a Fluttering Shutter. *Fourth IEEE International Conference on Biometrics: Theory Applications and Systems (BTAS).* 1-6.

[96] Miyazawa, K., Ito, K., Aoki, T., Kobayashi, K., and Nakajima, H. 2008. An Effective Approach for Iris Recognition Using Phase-based Image Matching. *IEEE Transaction of Pattern Analysis and Machine Intelligence*. 30: 1741-1756.

[97] Dehkordi, A. B. and Abu-Bakar, S. A. R. 2015. Adaptive Fuzzy Switching Noise Reduction Filter for Iris Pattern Recognition. *Jurnal Teknologi.* 73: 1.