Feature Fusion as a Practical Solution toward Noncooperative Iris Recognition

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Abstract – ***In noncooperative Iris recognition one should deal with uncontrolled behavior of the subject as well as uncontrolled lighting conditions. That means imperfect focus, contrast, brightness, and orientation among the others. To cope with this situation we propose to take iris images at both near infrared (NIR) and visible light (VL) and use them simultaneously for recognition. In this paper, a novel approach for iris recognition is proposed so that extracted features of NIR and VL images are fused to improve the recognition rate. When the images do not have enough quality due to focus, contrast, etc., effects of feature fusion is more pronounced. This is the situation in UTIRIS database, which is used in our experiments. Experimental results show that the proposed approach, especially in small training samples, leads to a remarkable improvement on recognition rate compared with either NIR or VL recognition.***

Keywords: Noncooperative iris recognition, feature fusion, visible and near infrared imaginary.

1 Introduction

With the rapid development of information technology, people increasingly depend on various information systems. A remained challenging problem is How to control the access to the important information. Biometric-based recognition is one of the most secure and convenient authentication technologies. Common characteristics are fingerprint, hand or palm geometry, retina, iris, face, signature, voice, keystroke pattern, gait and so on. Among the aforementioned biometric technologies, iris recognition is the most promising one for high security environments and noninvasive for users.

Iris is the colored portion of the exterior eye, which is embedded with tiny muscles that dilate and constrict the pupil size. The color, texture, and patterns of each person's iris are considered as unique as fingerprint. The iris patterns of an individual's eyes or those of identical twins are completely independent and uncorrelated [1]. Moreover, iris is a protected organ which is usually fixed during the human life and can be measured from a distance although obtaining high-quality iris images is a non-trivial task [2]. Regarding this issue, iris recognition can be considered as the most reliable biometric technology.

Various iris recognition methods have been proposed for automatic personal identification and verification. As a pioneering work [3], complex valued 2D Gabor wavelet was proposed by Daugman to extract the iris features and final iris representation was obtained by quantized local phase angles. His method is based on the property of the Gabor filters of offering the best simultaneous localization of spatial and frequency information. Experimental results indicate an excellent performance of this novel approach.

Wildes et al. [4] presented another iris recognition system. It constructs a Laplacian pyramid by iteratively applying a Gaussian lowpass filter and decimation operator to the iris image. Quantized differences between a level and its next lower resolution level yield the final representation. The similarity between new samples and stored templates are achieved using the normalized correlation. This method is reported to have good performance similar to the system proposed by Daugman.

Both systems of Daugman and Wildes require a strict image quality control, such as illumination and position. If these necessities are not satisfied completely, the feature extraction and matching may be greatly influenced. However, these demands are not easily satisfied in many field applications. Recently, other researchers including Boles and Boashash [5], [6], Ma et al. [7], [8], and Monro and Zhang [9] have contributed new methods to decrease the effects of lighting conditions and low quality captured images. Nevertheless, human's cooperative behavior is a common assumption in image acquisition process which restricts the application domains of iris recognition where the cooperative behavior is not expected. Thus, it seems that noncooperative iris recognition has been remained as a great challenge and needs to be addressed.

Currently, few researchers, e.g., [10] are working on noncooperative iris recognition challenges to obtain robust solutions against noisy captured iris images.

To the best of our knowledge, there is no paper to evaluate the performance of fused features derived from both

visible and near infrared images, except for a brief introduction in a previous work of our research team [11].
The goal of this paper is to show that the fusion approach can be considered as a reliable solution to the noncooperative iris recognition which involves simultaneous use of features derived from both visible and near infrared iris images. The motivation of this work is near infrared and visible light images have their own individual features. For example, visible images are widely affected by environmental illuminations and reflections and therefore the performance of such systems basically depends on the lighting conditions. In spite of such shortcoming, a useful property of these images is the capability of preserving fine details and useful information of iris texture; this property does not exist in the near infrared images.
The rest of the paper is organized as follows: In Section 2, we demonstrate the proposed fusion approach. Features were used in this paper are briefly introduced in Section 3. Experimental results are reported in Section 4. The paper is concluded in Section 5.

2 The Proposed Fusion Approach

Nowadays attempts to improve the performance of iris recognition systems mainly focus on system robustness, consistent performance under variability, registration speed and code compression. Nevertheless, noncooperative iris recognition challenges have remained and need to be addressed. For instance, current iris recognition systems require that the subjects stand close to the imaging camera (less than two meters) and look for at least three seconds until the required data are captured [12]. This cooperative behavior is regarded as a weakness since the domains of iris recognition are restricted, specially when the subjects' cooperation is not likely (e.g., criminal/terrorist seek and missing children) [10].
On the other hand, near infrared and visible light images have their own complementary features and integration of resultant information has been applied in many areas such as pattern recognition and images processing. For example in [13], feature fusion in this framework has been used to improve the target detection in an image sequence. In [14,15], feature and decision fusion based on visible and near infrared images have been applied to enhance the results of face recognition tasks. Due to successful implementation of this approach and the points raised in [11], a fusion approach may be helpful to address many challenges in iris recognition such as noncooperative behavior.
Near infrared iris images are less sensitive to the change of illumination and gray level distribution than visible light. On the other hand, the details including many tiny characteristics such as furrows, freckles, crypts, and coronas remain almost unchanged in visible light images while lost in the other. Accordingly, it is expected that a human authentication system which employs the advantages of these two databases will achieve a higher performance when dealing with low quality images due to focus, contrast, or brightness problems.
In other words, if the identification system encounters the uncontrolled lighting conditions or if the performance of feature extraction algorithm is highly affected by the quality of iris texture, the overall system performance which use features based on only near infrared or visible images will be degraded intensively, unless a feature fusion strategy is employed to compensate these undesirable effects. One simple and practical way of integration both kinds of features is to place the codes obtained from both databases consecutively for every individual person in database. One of the major drawbacks of this method is that the resulting code has twice the length of each initial code which results in more computational burden and more time-consuming process consequently. Thus, this technique makes its real-time implementation more difficult and costly and a larger amount of data is needed for training.
As an alternative approach, utilizing other feature fusion techniques such as Fuzzy Integral or Ordered Weighted Average (OWA), which lead to equal code length as the initial codes, in the sense of computational burden are more efficient
An ideal system is capable to recognize a large number of test samples while using minimum number of train samples in spite of low quality images. From this point of view, we will show that feature fusion approach can be inferred as a reliable solution to achieve maximum recognition rate utilizing minimum number of train samples. Consequently, this approach can lead to individual system identification with low capacity mass storage device. Two main advantages of fusion approach which make it a powerful framework to deal with these aforementioned challenges are demanding small training samples and the no need to a cooperative behavior.

3 Feature Extraction

The most important step in human identification system based o iris biometric is the ability of extracting some unique attributes from iris which help to generate a specific code for each individual. In this paper discrete cosine and wavelet transforms were used for analyzing the human iris patterns and extracting features from them. In the rest of this section, application of mentioned transforms has been shortly demonstrated.

3.1 DCT Based features

In [16], a new approach to human iris recognition based on the 1D Discrete Cosine Transform (DCT) has been proposed. Their experimental results indicate the good performance of DCT based features on both bath and CASIA datasets. In this subsection, we briefly introduce DCT and then its application to obtain features.
The DCT is a real valued transform, which calculates a truncated Chebyshev series possessing well-known minimax properties and can be implemented using the

Discrete Fourier Transform (DFT) [17]. A common DCT formulation has been shown below

$$C_k = \frac{2}{N} w(k) \sum_{n=0}^{N-1} x_n \cos(\frac{2n+1}{2N}\pi k), \quad 0 \le k \le N-1 \quad (1)$$

$$x_n = \sum_{n=0}^{N-1} w(k) C_k \cos(\frac{2n+1}{2N}\pi k), \quad 0 \le k \le N-1 \quad (2)$$

$$w(k) = \frac{1}{\sqrt{2}}, k = 0 \; and \; w(k) = 1, 0 \le k \le N-1 \quad (3)$$

Like other transforms, the Discrete Cosine Transform (DCT) attempts to decorrelate the image data. After decorrelation each transform coefficient can be encoded independently without losing compression efficiency. Some of important properties of DCT are as below

- Separability
- Decorrelation: the principle advantage of image transformation is the removal of redundancy between neighboring pixels. This leads to uncorrelated transform coefficients which can be encoded independently.
- Symmetry: This is a very important property, since it shows that the basis functions can be pre-computed offline and then multiplied with the sub-sequences. This reduces the number of mathematical operations (i.e., multiplications and additions) thereby rendering computation efficiency.
- Energy Compaction: This allows the quantizer to discard coefficients with relatively small amplitudes without introducing visual distortion in the reconstructed image. DCT exhibits excellent energy compaction for highly correlated images.
- Orthogonality: this property renders some reduction in the pre-computation complexity.

Here, it is important to keep in mind that DCT is not the real part of the Discrete Fourier Transform (DFT) despite their similarity. This can be easily verified by inspecting the DCT and DFT transformation matrices.

Although the main application of DCT is in image compression, recently it has been used as a feature extraction method in face recognition [18]. In the following, the main feature extraction process (algorithm) is briefly explained and further details can be found in [16]. At first, in order to perform noise reduction, some preprocessing steps must be carried out. Then, the normalized iris texture must be partitioned into several overlapped patches which its size in vertical and horizontal directions can be determined using extensive experiments to achieve a higher performance rate. Thereafter, using ¼ hanning window, resolution of horizontal direction is degraded and consequently every patch reduced to a column vector which called 1D patch vector. In order to reduce spectral leakage during the transform, every 1D patch vector is windowed by means of a hanning window. The differences between the DCT coefficients of adjacent patch vectors are then calculated and a binary code is generated from their zero crossings.

3.2 Wavelet Based features

As we know, the approximation coefficients matrix and details coefficients matrices (horizontal, vertical, and diagonal, respectively), are obtained by wavelet decomposition of the input image. Poursaberi [19] got the 3-level wavelet decomposition detail and approximation coefficients of projected iris image. Desired feature vector is formed by combining features in the LH (Lowpass-Highpass) and HL (Highpass-Lowpass) of level-3. Then the binary code was obtained by replacing positive phase entities by 1 and negative by zero. This method was implemented on cassia ver.1 and experimental results demonstrated the effectiveness of wavelet based features.

4 Experimental results

In this section, at first, we describe our own data collection at the University of Tehran and next, the experimental results on this database are reported.

4.1 Data Collection

Recently, in our biometric research team at University of Tehran, we gathered a new database (UTIRIS) consists of two sessions with 1540 images, 770 captured in visible light and 770 in NIR illumination. Both sessions hold 158 eyes relating to 79 subjects (Right and Left eyes). Images in VL Session have been captured in high resolution with 3 mega pixels where they have been downsampled by a factor of 2 in each dimension to have the same size as NIR captured images [20]. Despite of high resolution captured images; both visible and near infrared iris images are highly noisy due to focus, reflection, eyelashes, eyelids and shadows variations that make the UTIRIS a challenging iris database. In despite of highly noisy images, it is clear that the UTIRIS can not cover the all aspects of noncooperative iris recognition; but it can be considered as the first iris database which contains VL and NIR images captured from same persons to address the situations where the cooperative behavior is not expected. Fig. 1 shows some samples of UTIRIS database.

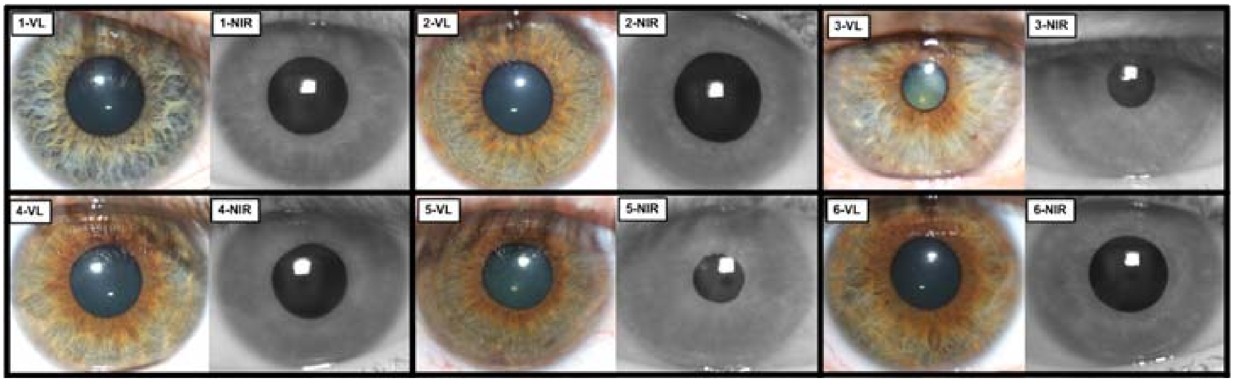


Fig. 1 some samples from UTIRIS database. Six pairs of images are shown, where for each pair the left image is taken at visible light, while the right one is taken at near infrared light

4.2 Description of Experiments

Among total UTIRIS database, we specifically consider iris images of 114 individuals and evaluate the accuracy of the system in different possible numbers of test and train samples. Although using only one train sample may appear meaningless at first, our aim is to highlight the effectiveness of the fusion approach to improve the obtained results in this condition based on only visible or near infrared datasets.

Firstly, the performance of DCT Based features [16] was evaluated on both parts of the database separately. Next, to assess our claim, extracted features derived from visible light and near infrared images were fused using augmentation and OWA techniques and the evaluation process was again carried out. Comparing the results indicates the advantages of the proposed approach especially in the small training samples which could be found as a new way to develop human system authentication using less memory space than traditional systems. The same process was done for wavelet based features [19].

Experimental results (as shown in Tables 1-2) indicate the superior performance of the results based on fusion approach in comparison with the case which only one dataset has been utilized. In the all cases, augmentation technique gives rise to better recognition rate than OWA operator which is expected, since in latter case, some worthful information is lost. When there is a small number of training samples, using augmentation technique leads to remarkable improvement in comparison with OWA. Nevertheless, these techniques yield approximately the same results in other cases which imply the superiority of OWA method due to less computational cost.

The ROC curves have also been plotted to compare the results from another point of view as depicted in Fig. 2 From Fig. 2, the fusion approach has the better recognition rate at in any given FAR, and also has the lower amount of FRR.

The separability between matching and mismatching irises in Fig. 3 demonstrates to what extent the fused features can enhance the recognition rate. As depicted in Fig. 3, the separability measure in the case of fused features is larger than the two other cases. This result is in accordance with the previous observations in Tables 1-2 and Fig. 2.

Those images that failed in the recognition process are again analyzed. We realized that all of the images are damaged partially with eyelid or eyelash occlusion. After putting out these kinds of occluded and blurred images and using more than two training samples, 100% recognition rate is achieved.

5 Conclusion

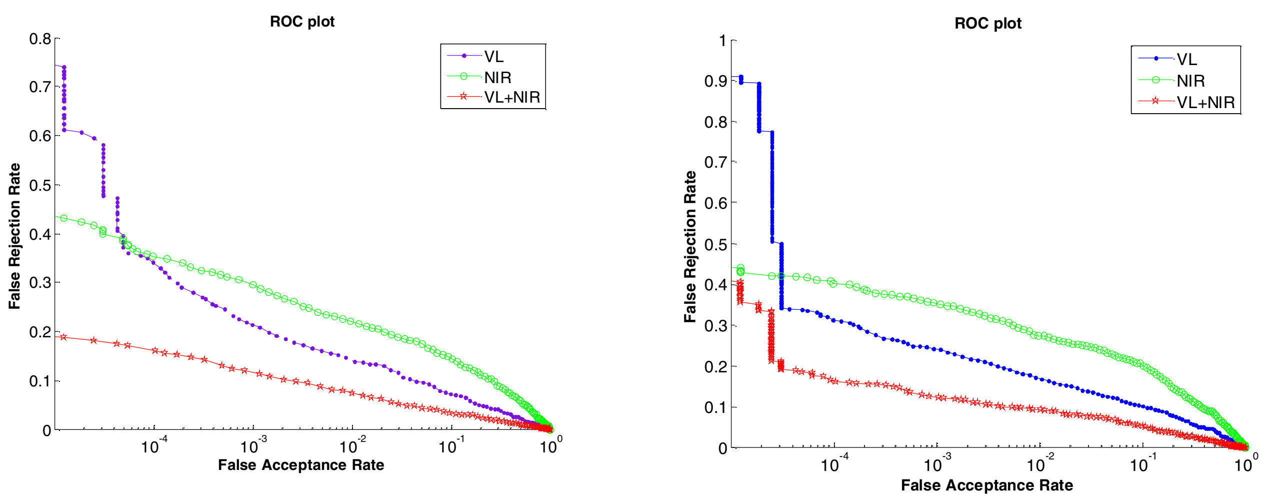
In this paper, we proposed a fusion approach to address noncooperative iris recognition challenges. This issue results in low quality iris images and poor performance of human system authentication consequently. The work was motivated by the individual features of near infrared and visible light iris images. OWA and augmentation techniques were employed to perform the feature fusion task. The experimental results indicate the good performance of the proposed approach especially in small training samples. The proposed approach can be found as a new way to develop human system authentication using less memory space than traditional systems. The best recognition rate was achieved using augmentation technique based on DCT features, but it led to more computational burden and more time-consuming process than OWA. As shown in Tables 1-2, utilizing OWA operator was more reasonable when the number of training sample is not small. In this case, the both computational cost and recognition rate are improved. Generally speaking, the fusion approach can be considered as a reliable solution to challenges caused by noncooperative subjects' behavior and a practical way to develop human system authentication with low capacity mass storage device.

TABLE I
UTIRIS CLASSIFICATION RESULTS DERIVED FROM DCT-BASED FEATURES

Number of Training Samples	Error rate on			
	Visible Light Images	Near Infrared Images	Near Infrared & Visible Light Images	
			OWA	Augmentation
1	13.8 ± 1.3%	18.4 ± 2.2%	8.3 ± 1.0%	4.8±0.8%
2	7.9 ± 1.0%	8.9 ± 1.2%	3.2 ± 0.9%	1.8 ± 0.5%
3	6.5 ± 1.0%	5.5 ± 1.2%	2.0 ± 0.7%	1.0 ± 0.4%
4	3.6 ± 1.3%	4.6 ± 1.0%	0.8 ± 0.7%	0.7 ± 0.2%

TABLE II
UTIRIS CLASSIFICATION RESULTS DERIVED FROM WAVELET-BASED FEATURES

Number of Training Samples	Error rate on			
	Visible Light Images	Near Infrared Images	Near Infrared & Visible Light Images	
			OWA	Augmentation
1	17.8 ± 1.4%	26.4 ± 1.5%	14.9±1.2%	8.3 ± 0.8%
2	9.3 ± 0.6%	15.3 ± 1.3%	6.4 ± 1.2%	3.2 ± 0.8%
3	6.2 ± 1.4%	11.0 ± 1.8%	2.3 ± 1.1%	2.0 ± 0.4%
4	5.5 ± 0.2%	7.9 ± 1.8%	3.3 ± 0.8%	1.5 ± 0.7%



(a) DCT-based features

(b) Wavelet-based features

Fig. 2 ROC plots using (a) DCT-based, (b) Wavelet-based features. Each plot shows ROC curves for Visible Light (VL) , Near Infrared (NIR), and Fusion of extracted features

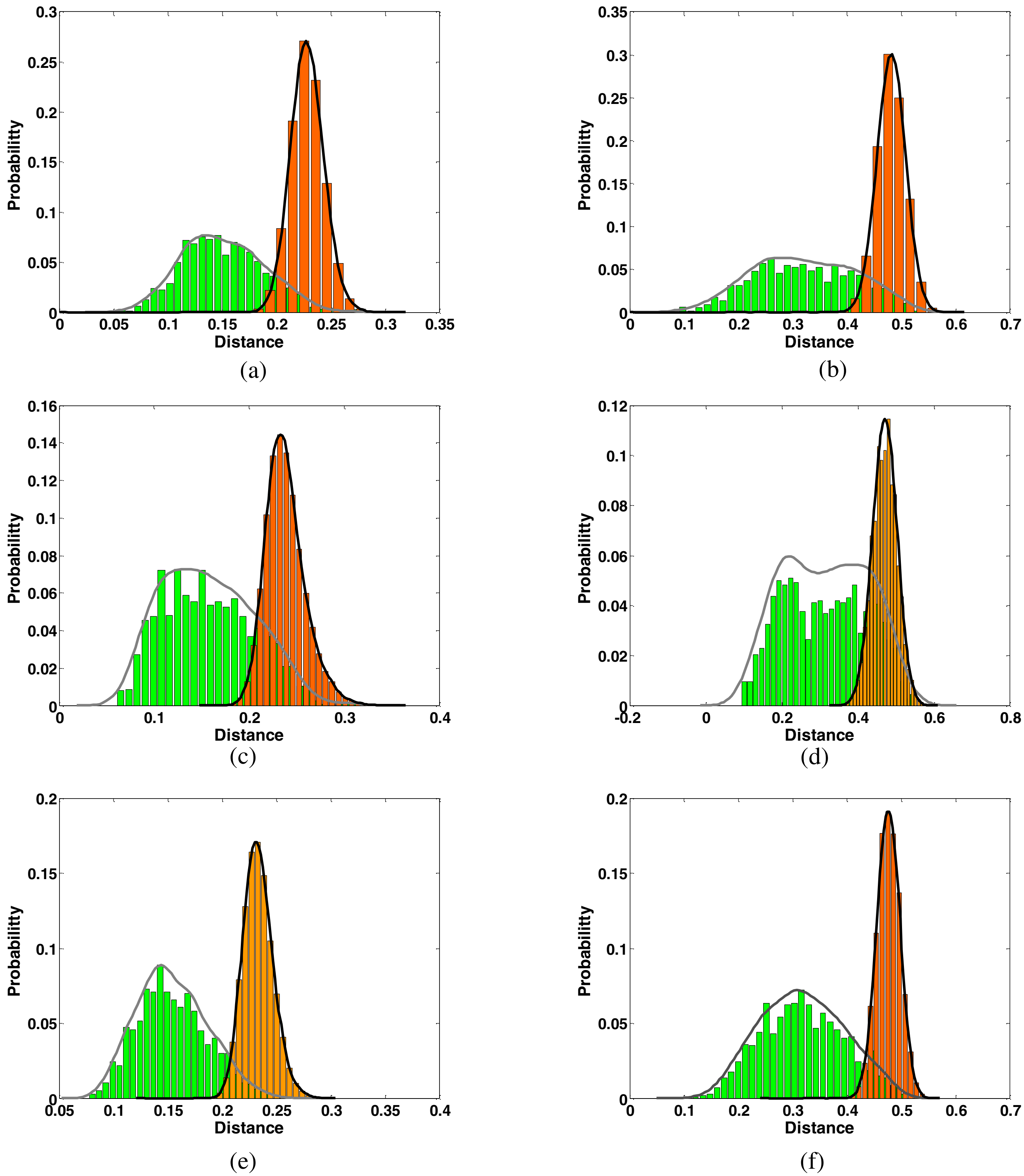


Fig. 3 Probability distribution curves for matching and mismatching Hamming distances extracted from the (a) visible light images with DCT-based features, (b) visible light images with wavelet-based features, (c) near infrared images with DCT-based features, (d) near infrared images with wavelet-based features, (e) near infrared+ visible light images with DCT-based features (Augmentation), (f) near infrared+ visible light images with wavelet-based features (Augmentation).

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