Rank Level Fusion of Multimodal Cancelable Biometrics

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Abstract—**Cancelable biometrics is newly emerged biometric technology that can provide the protection over different attacks to a biometric system. In this paper, we have presented a multi-level random projection on face and ear biometric traits. The multiple random projections are conducted using multiple random projection matrixes. From multiple random projections, we have generated multiple templates for biometric authentication. Therefore, proposed method can provide better template security and better feature quality. Multiple cancelable templates are used for recognition purpose and rank level fusion is applied to generate final decision from multiple ranks. As per our knowledge, we have applied rank level fusion on cancelable multimodal biometric system for the first time. A detailed validation and the performance analysis of the proposed algorithm on a virtual multimodal cancelable face and ear database are presented.**

Keywords-Score level fusion, multimodal cancelable biometrics; template security; cancelability; random projection

I. INTRODUCTION

Multimodal Biometric System is a relatively new alternative to Unimodal Biometric System. Multimodality can be achieved in various ways: such as combining multiple biometric traits, selecting distinct feature sets from the same source of biometric, using separate sensors, fusing the decision of individual biometric system, etc. [7]. In our system, we have used diverse feature sets from different biometric traits. From the literature, it is found that multimodal biometric system often outperforms a unimodal biometric system in terms of accuracy and reliability [3]. It can solve some common problems of unimodal biometric system such as intra-class variability, interclass similarity, non-universality, sensitivity to noise and other issues. Multimodal biometric system can improve the performance of a biometric system in a number of aspects, including accuracy, circumvention, resistance to errors and spoof attacks [3]. Multimodal biometric systems are more secure compared with unimodal systems in terms of authentication accuracy [4].

Individual's biometric traits are stored on a template database during both the training and the matching. The most important part of the biometric system from the point of view of security and privacy is the template database. Previous, studies [2] [5] have shown that the raw image or text can be recovered from the template stored within the database. A first approach to deal with biometric security and privacy was to store the transformed version of original template [2] [5]. Ross, el., al., 2007 reconstructed fingerprint image from stored minutiae points. In previous research on biometric template protection, authors suggested the dependency of cancelable biometric algorithm on security, discriminability, recoverability, performance and diversity of the system [1] [6] [8]. They noted that it should be computationally hard to reconstruct the original template from the transformed template. The discriminability of the original biometric template should not be lost after the cancelable transformation as well as performance. On the other hand, the revocability and diversity are the two most important characteristics of Cancelability.

In the recent years, the link between the cognitive informatics community and biometric security has grown stronger. It is evident from the number of publications that span both domains, and deal with issues of applying intelligent techniques to biometric processing, and with developing new cognition methods for biometric and security applications and research [9] [32]. Computational intelligence finds its many uses in biometric domain [33] [35]. In addition, virtual reality also benefits from novel biometric methods [34]. The concept of cancelable biometric or cancelability has become really popular very recently [8]. This new trend focuses on how to transform a biometric data or feature into a new one so that users can change their single biometric template in a biometric security system. Up until now, multimodal system cancelability has not been considered. However, this can be argued that template protection is even more crucial in such systems. Multimodal biometric system uses numbers of biometric credentials so it is cooperative to the attackers to get more evidence if they manage to break the system. Once templates from the multimodal system are compromised, individual loses all the sensitive data stored in the current security system, and all other systems related to that individual. This is why it is crucial for a multi-biometric system to provide the template security and cancelability. It can be claimed that using cancelability for each biometric trait separately in multimodal

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biometric system can solve the problem. However, this is not as easy as it looks; the solution may be costly in term of computation efforts and performance. If one trait is compromised, similar method can be used to break other traits. Another concern can be key protection and storage; system needs to issue key for each biometric trait. In this paper, we tackle the above problems and present a novel solution for cancelable biometrics in a multimodal system. We develop a new cancelable biometric template generation algorithm using random cross folding of multiple biometric traits, random projection and transformation-based feature extraction and selection. Performance of the proposed algorithm is validated on a virtual multi-modal face and ear database. Specifically, algorithm security is validated by issuing different original and fake keys for different subjects of the database. Algorithm discriminability remains high because of the similar cross fold indices and random projection matrix (vectors) for a class. Similarly, revocability and diversity are ensured by issuing different sets of keys for training and testing process. It is to the best of our knowledge; the first cancelable multimodal system developed using this novel methodology.

Proposed methodology is briefly described as follows. At the first step, the multi-fold random selections of raw features are made for each biometric trait. It gives the system a random mixture of raw features from two biometric traits. The process can be named as random biometric fusion. The outcome of this process is similar to watermarking of face on ear template and vice versa. In the second step, fused samples of each fold are then projected using orthogonally transformed random matrix from which cross fold indexes are selected. After the random projection, a template is generated by projecting fold2 by fold of randomly projected template. The final set of templates is used to find Principal Component Analysis (PCA) based feature. Point to be noted that this is an individual PCA the main purpose is to compress the templates. Templates from PCA are used for training and testing. Since we have generated *n* templates from two different biometric traits, in the testing phase similar *n* templates are used to get the final decision using rank level fusion. The system is tested on virtual multimodal databases for face and ear biometrics, considering both cancelability and performance. The results presented in experimentation section show that the developed random projection method for cancelable biometric satisfies the template protection requirements and the multimodality of biometric system.

II. RELATED WORK

There are different levels of attacks that may take place in a biometric system at sensor level, application level, database level, etc. [2] [29] [30] [31]. Therefore, biometric systems should be intelligent in computing and processing. There are numbers of methods for intelligent computing that were developed very recently [10] [27]. Cancelable biometric system is a type of intelligent system that can protect the database from template level attack. Biometric system with cancelability or template protection scheme can defend the biometric database from security threats.

From the literature review, we have summarized the categories of cancelable biometric system. Based on the number of biometrics used, cancelable biometric system can be divided into Unimodal and Multimodal Cancelable Biometric system. In the unimodal system, single biometric traits are used for cancelability. The multimodal cancelable biometric system uses multiple biometric traits. Based on an order of cancelability both multimodal and unimodal cancelable biometric system can be divided into two main categories: First-Order Cancelable Biometric System and Second Order Cancelable Biometric System.

A. First Order Cancelable Biometric System

In this type of system, biometric data are transformed once into a cancelable feature from original or extracted biometric feature. Cancelable biometric template can be generated using either biometric cryptosystem or transformation based system. In biometric cryptosystem a secrete key is linked with the biometric data [11] [12] [13]. This key can be selected randomly, or it can be generated from biometric data. Two most popular biometric cryptosystems are the fuzzy commitment scheme [11] and fuzzy vault scheme [12]. Goh et. al., 2003 presented cancelable face biometric using biometric cryptosystem. In their work, he generated key from face template. Research work presented throughout the paper [14], is an example of a transformation-based system where authors transformed fingerprint into another domain using Cartesian, radial and functional transformation. They are not combining transformation to obtain the cancelable template, thus this is a first-order system.

B. Second Order Cancelable Biometrics

In second order cancelability, biometric traits are transformed into a cancelable template twice. In each level, both biometric cryptosystem and transformation-based systems can be used. It is also possible to repeat the same scheme twice for cancelability. Ratha et. al., 2007 first proposed the concept of cancelable biometrics (or cancelable template). He provided the basics of the cancelable biometrics but did not address the discriminability issues. Later salting (cryptosystem) of biometrics was introduced based on combining a user defined key or password to increase the between-class variation and enhance the discriminability. However, a transform-based approach also takes the original biometric template and the user-specific key to enhance the discriminability of the transformed templates [15]. The advantage of the transformed template is cancelability. Second order of a cancelable system can also be designed based on biometric cryptosystem and transformation-based approach [8]. Their proposed approach retains the advantages of both the transform-based approach and biometric cryptosystem approach. Recently (Paul & Gavrilova, 2012) presented a second order multimodal cancelable biometric system using random projection.

There are also groups of methods that can exploit Multi-order cancelability. In this type of system, several cancelable mechanisms are applied on biometric data. The method presented within this paper belongs to Multi-order cancelable biometric system.

In this method, multimodal approach is presented using cross-folding random indexes of template to achieve the multimodal cancelable biometric template. There are a number of benefits to the proposed method. Applying the multimodal technique in feature level, the proposed Cancelable Multi-biometric System can enhance the interclass variability and thus improves the performance of the multimodal system. Furthermore, the main complications of multimodal biometric systems are memory and computational complexity during the training and testing. In the traditional multi-biometric system, all the biometric traits are stored within the database and used for computation. Proposed Cancelable Multi-biometric System can fuse all the templates for different biometrics into one single multimodal biometric trait that can reduce the database size and computation during the identification and verification process. The paper is organized into two main sections. In the section III the proposed method is presented. In section IV the experimental result is presented. Finally, the paper is concluded with future direction of the research.

III. Proposed Method

A. *Proposed Architecture*

Proposed cancelable multimodal biometric system has three major phases a) training phase, b) testing phase and c) rank level fusion phase. Feature processing is similar in both training and testing process. Feature processing part is divided into three major parts: i) Random Cross folding for feature fusion, ii) random projection iii) applying Principle Component Analysis (PCA) to the feature quality. Finally, the cancelable template is used to model the k-NN classifiers for performance analysis. Figure 1 shows the block diagram of the multimodal cancelable biometric system.

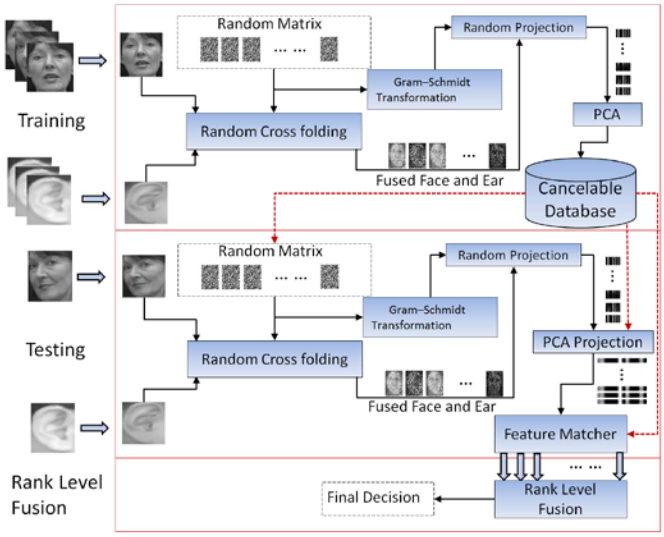

Figure 1. Block Diagram of the proposed Multimodal Cancelable Biometric System. Training and testing phases are dipicted briefly.

The main goal of the process is to generate the cancelable templates from face and ear biometric. Since this process is taking several random matrixes to generate many versions of cancelable template, it might take more database space to store the templates. To reduce the database space required we have applied PCA on the generated temples for single sample pair of face and ear. Generating multiple templates and using them for testing purpose can improve the performance and cancelability. One door is open for us to select random templates for recognition purpose to protect from feature override attack in a biometric system.

In the testing phase, user will use a key and biometrics (face and ear) to grant the access to the system. The keys are the compressed random matrixes that are used in the training purpose in both random cross folding and random projection. The same process as training is used in testing to generate the templates. We can take several templates for recognition purpose but in the decision level, we can also mix some flavor of cancelability in decision. Since it is unknown, which template is going to be selected during the decision it will be really hard to estimate the template. Therefore, we have used all the templates in training and testing. To generate the final decision we have used the ranks of each template for an individual. In the first stage of the transformation is random cross folding. The outcome of the process is two sets of a feature that are cancelable. Random indexes are used to generate two folds. Both folds are then projected using orthogonally transformed random matrix. Randomly projected Fold 1 is then used to project Fold 2.

B. *Multiple Biometric Traits Fusion*

In this paper, we proposed to achieve the cancelability using random cross-folding and random projection method. Figure 2 shows the random cross folding using n random matrixes. First, we have taken a set of random matrixes R and one face (F) and one ear (E) biometric trait, $R = \{R_1, R_2, R_3 \cdots R_n\}$, where are is the set of n random matrixes. Once we have specified the random matrixes we used a thresholding method to find the random indexes. This threshold is computationally generated from the random matrix itself, which is unknown to the user and system administrator of the biometric system. After the binarization of R using the threshold, we get some random indexes of 0 and 1. r is the set of random indexes computed form set R and r is generate from $r = \{r_1, r_2, r_3 \cdots r_n\}$. r is then used to find the randomly cross folded templates of fused face and ear. f_1 and f_2 are presented using the following equations to compute the fused templates, $f_1 = \{r_1 \bullet F, r_2 \bullet F \cdots r_n \bullet F\}$ and $f_2 = \{(1-r_1) \bullet F, (1-r_2) \bullet F \cdots (1-r_n) \bullet F\}$. The similarly the ear templates are generated using the random indexes using the e_1 and e_2, $e_1 = \{(1-r_1) \bullet E, (1-r_2) \bullet E \cdots (1-r_n) \bullet E\}$ and $e_2 = \{r_1 \bullet E, r_2 \bullet E \cdots r_n \bullet E\}$. Once we have selected raw features from both face and ear then we fused them together using simple feature fusion. This operation is simply dot addition, which means it fills the black indexes of face using ear indexes. Let us assume that fe is set of fused features and we have fe_1 and fe_2 from two folds. fe_1 and fe_2 are presented in terms of $fe_1 = \{f_1 + e_1\}$ and $fe_2 = \{f_2 + e_2\}$. Feature fusion of multiple biometric traits is a highly important step for multifold random selection. Raw biometric features are randomly divided into two parts.

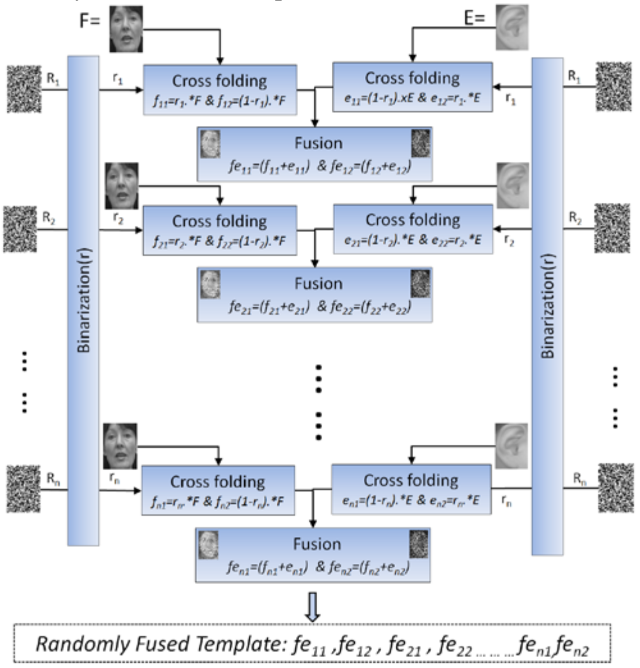

Figure 2. Block diagram of cross folding of two biometric traits (face and ear) for the proposed *n*-times cross-folding for proposed multimodal cancellable biometric system.

For example, two folds generated from one face and one ear template is explained here. First, a pseudorandom number generation algorithm is used to split the raw features into two parts. Face biometric template is divided into Face-Fold 1 and Face-Fold 2. Similarly, ear template is divided into Ear-Fold 1 and Ear-Fold 2. Finally, Face-Fold 1 and Ear-Fold 2 are combined to achieve the Face-Ear Fold 1 and Face-Ear Fold 2. Similar-sized template of 75x50 for each fold is used for consistency of the system for feature extraction and classification. Therefore, the Face-Ear Fold 1 and 2 are in same size as the template size, 75x50. These folds are then processed using proposed cancelable templates generation algorithm. Figure 2 depicts the block diagram of proposed cross-folding method. Cross folding fuses the face and ear biometrics into two templates of Face-Ear. First template is a watermark of face on an ear. Similarly, in second template is a watermark of an ear on a face. However, this process is not fixed in terms of raw feature selection. Raw features are randomly selected to generate the Face-Ear template so system is able to generate multiple templates from one set of face and ear biometric. Another advantage to this process it creates new relationship among biometric traits.

C. *Random Projection for Cancelability*

Random projections are applied on fe_1 and fe_2. Let P is the projection matrix calculated from R using Gram-Schmidt orthogonal transformation. From R we found the set of projection matrixes $P=\{P_1,P_2,P_3\cdots P_n\}$. The random projection is calculated using $P'\times fe_1$ and $P'\times fe_2$. Therefore, the sets after the random projection become rfe_1 and rfe_2. Figure 3 shows the block diagram of random projection and finally fused templates. rfe_1 and rfe_2 can *be* represented as $rfe_1=\{P_1'\times fe_{11},P_2'\times fe_{12},\cdots P_n'\times fe_{1n}\}$ and $rfe_2=\{P_1'\times fe_{22},P_2'\times fe_{22},\cdots P_n'\times fe_{2n}\}$. After the random projection, we have projected rfe_2 by using erf_1. Finally, the template set T is found from the face and ear biometric traits. $T=\{rfe_{11}'\times rfe_{12},rfe_{21}'\times rfe_{22},\cdots rfe_{n1}'\times rfe_{n2}\}$.

Johnson and Lindenstrauss [20] first develop the idea of random projection. Number of researchers used random projection for cancelable biometric system [8] [15] [21]. The main goal of random projection is to project vector on to a reduced dimensional space called Euclidian space [20] [22]. The main property of the random projection is to keep the Euclidean distance similar in some extent before and after the projection of vector. Random projection changes the vector and transforms into new vector, but it keeps the statistical property to the original [21].

In the proposed method, random projection matrix is calculated in two steps. In the first step, a random matrix is generated based on the random seed. In the second step, random matrix is transformed into orthogonal matrix using Gram-Schmidt orthogonal transformation. The Gram–Schmidt transformation is used to orthonormalize a set of vectors (2D matrix) in Euclidean space R^n [23]. This transformation allows the projection to keep the distance of the projected features same in Euclidean space.

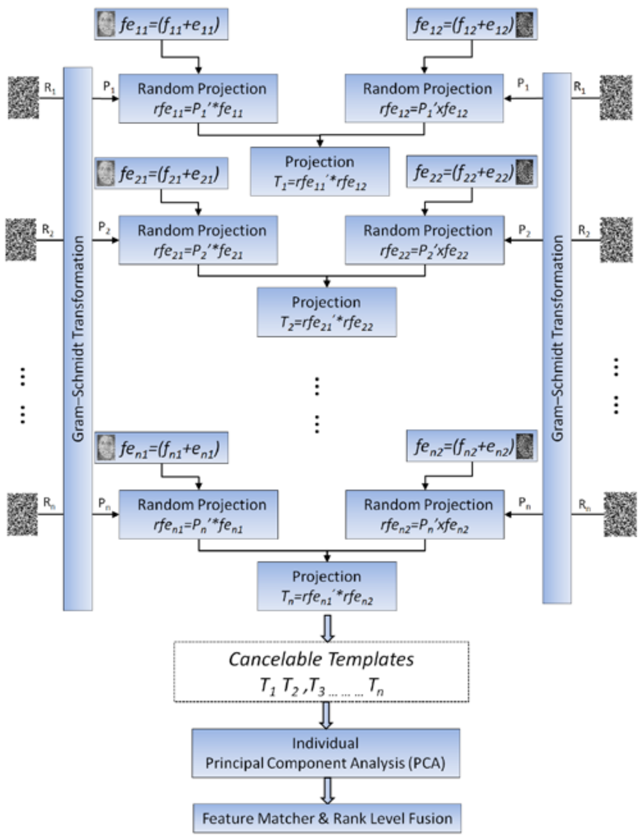

Figure 3. Block Diagram of random projection for multiple cross folded template to generate final cancelable template set for an individual.

D. Principal Component Analysis

In 1991, Pentland and Turk introduced Eigenface method to address two-dimensional recognition problems in their fundamental paper "Eigenface for Recognition" [16]. They have used Principal Component Analysis (PCA) to extract feature for face detection and recognition system. From that revolution, PCA becomes a standard tool for modern data analysis in different fields such as biometrics, image processing, machine learning, etc. For the complex dataset, PCA is a simple, non-parametric method to extract features [17]. The templates from the set T are used to generate the final templates using PCA.

Generally, a linear orthogonal transformation $v = W_u$ (where u is the observation vector) is used such that the retained variance is maximized [18] [19]. Alternatively, PCA is viewed as a minimizer of reconstruction error. It turned out that these principles (variance maximizer or reconstruction error minimizer) leads to a symmetric eigenvalue problem. The row vectors of W correspond to the normalized orthogonal eigenvectors of the data covariance matrix. Let us denote the data covariance matrix by $R_u = E\ \{uu^T\}$ where the superscript T denotes the transpose of vector or matrix. Then the SVD of R_u has the form

$$R_u = U_u D_u U_u^T$$

where U_u is the eigenvector matrix and D_u is the diagonal matrix whose diagonal elements correspond to the eigenvalues of R_u. Then the linear transformation W for PCA is given by

$$W = U_u^T$$

For dimensionality reduction, one can choose p dominant column vectors in U_u which are the eigenvectors associated with the p largest eigenvalues in order to construct a linear transform W.

E. Rank Level Fusion

In the classification stage, test templates for one individual are tested against the training set. Using the *k*-NN classifier ranks of the each training set is calculated. From the ranks, using the borda count final decision is taken. As from the test setup, depending on the number of random projections number of ranks varies. We have taken first three ranks for each template. From these ranks of each template, final decision is made. For example, if our experiment takes *n=5*, we can generate 5 templates for one individual. From these 5 templates we can find total 15 ranks and final decision is made form 15 ranks. In future, we may try some other method of rank level fusion, for example, fuzzy logic based rank level fusion, logistic regression etc.

IV. Experiments

A. Experimental Setup

We have designed cancelable multi-biometric system using MATLAB 2009b and C# on Intel Core i7 2.2GHz Windows 7 Enterprise workstation. Developed system is menu-driven Graphical User Interface (GUI) that supports both 32-bit and 64-bit version of Windows. Multimodal virtual database is preprocessed and saved as MATLAB standard database file with mat extension. Each biometric trait is scaled into the 75x50-resolution grayscale bitmap image. GUI is designed using C# that includes a button to selection of database for connection. As soon as a database is connected, it automatically retrieves all the dimension information and number of samples form the database. Developed system has a capability of processing biometrics of different resolution and this processing is automatic. User can also input number of fold for cross validation process.

To validate the proposed methodology, we have designed comprehensive test settings involving five biometric databases. The tests were intended to examine system behavior in respect to cancelability, specifically on recognition performance of the cancellable system (the higher the better) and on possibility to reconstruct original template from cancellable template (the lower the better). To ensure successful training, database selection and pre-processing is necessary and crucial. For testing our method, we have used a virtual database that contains data form two different unimodal biometric database for face and ear. For face, FERET [24] VidTIMIT [25] and Olivetti Research Lab Database [28] were chosen. We have taken variety of database and randomly combine them to generate virtual database. A subject selection from the face database was random and different sets of virtual database were generated. Two databases called University of Science and Technology Beijing (USTB) Image Database I & II [26] for ear are selected to generate virtual multimodal Face-Ear. To generate the virtual database all the images of the ear databases are used. Table 1 shows the virtual database setup for three sets of virtual database.

TABLE I. RANDOMLY CREATED VIRTUAL MULTIMODAL DATABASE, EACH SET IS DESIGNED USING DIFFERENT NUMBERS OF SUBJECTS FROM DIFFERENT DATABASES. FOR EACH SUBJECT THREE IMAGES ARE TAKEN SHOWN BESIDE NO OF IMAGE.

SET		SET-1	SET-2	SET-3	SET-4	SET-5
Face	FERET	90 (3)	110 (3)	100 (3)	80 (3)	70 (3)
	VIDTIMIT	26 (3)	10 (3)	10 (3)	30 (3)	40 (3)
	AT&T	27 (3)	23 (3)	33 (3)	33 (3)	33 (3)
Ear	USTB I	66 (3)	66 (3)	66 (3)	66 (3)	66 (3)
	USTB II	77 (3)	77 (3)	77 (3)	77 (3)	77 (3)
No. of Samples		858	858	858	858	858
Dimension		75x50	75x50	75x50	75x50	75x50

B. *Experimental Results*

In the experiment, the goal was to check the performance of multimodal cancelable biometric system using the proposed method. Performance of cancelability depends on both recognition accuracy and the cancelability of the biometric system. To achieve this goal, the following scheme is designed. The performance of the proposed system is presented using Cumulative Match Characteristic curve.

The system is tested on variety of measures such as improvement of classification accuracy, improving and keeping the performance of multimodal biometric system. The result of the multimodal and unimodal cancelable biometric system is also compared. For the final performance, ten-fold cross validation is used on our virtual multimodal database using *k*-NN classifier. Properties of cancelable biometric are tested, such as keeping interclass variability (improved performance), issuing new template, and reverse processing to generate an original template. As a result, it is shown that using cancelable biometric template achieved a better performance than the matching performed on original image. Figure 6 shows the CMC curve for cancelable biometric template and the original face and ear templates. Results presented in the figure ensure that cancelable features do not degrade discriminability.

The first step is to optimize the number of random projections or number of cross folding. We have tested the system for different number of cross folds. The performance over different n is presented in figure 4. From the analysis of the result we found that for $n=11$ or $n=12$ or $n=13$ system provides best performance and the performance is almost 100%. The rest of the experimental result is conducted for $n=11$.

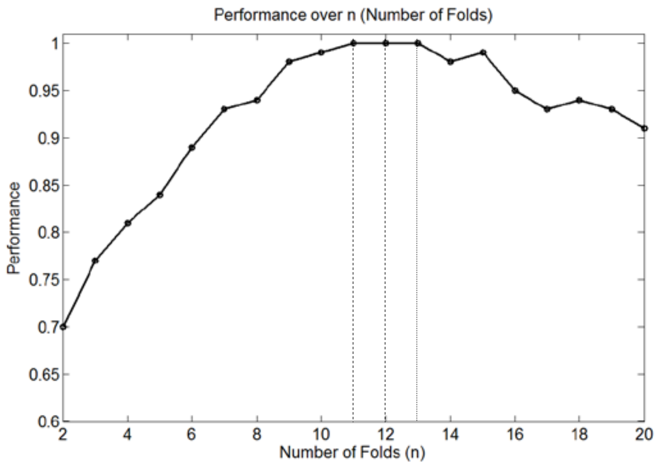

Figure 4. Performance of the system over number of foldes used.

Figure 5 shows the performance of proposed method. We have tested the system for both unimodal and multimodal configuration to test the multimodal cancelable system using rank level fusion. Cancelable template gives better performance than original templates. This performance is tested over unimodal face and ear based system. By using both face and ear, it should improve the performance comparatively with unimodal face or ear biometrics. CMC curves of unimodal face, ear, and the proposed cancellable multimodal method are plotted in figure 5. From figure 5, we can see that the rank one recognition rate of unimodal face and ear are 64% and 70%, respectively. However, rank one recognition rate of the proposed method is 84%. It is shown that the proposed method obtained 100% recognition rate within rank eight while unimodal face and ear obtained 100% recognition rate within rank 10 and 11, respectively.

Figure 6 plots the CMC curves of traditional multimodal and the proposed cancellable multimodal face and ear recognition approaches. It demonstrates 13% improvement in rank one recognition rate of the proposed method over traditional multimodal face and ear recognition approach.

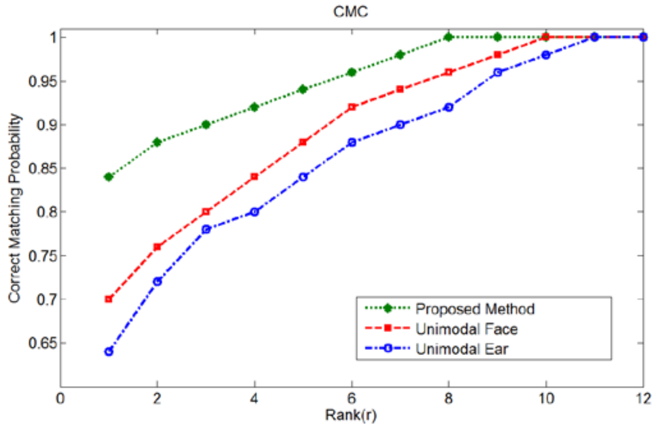

Figure 5. CMC curve for proposed method and unimodal face and ear.

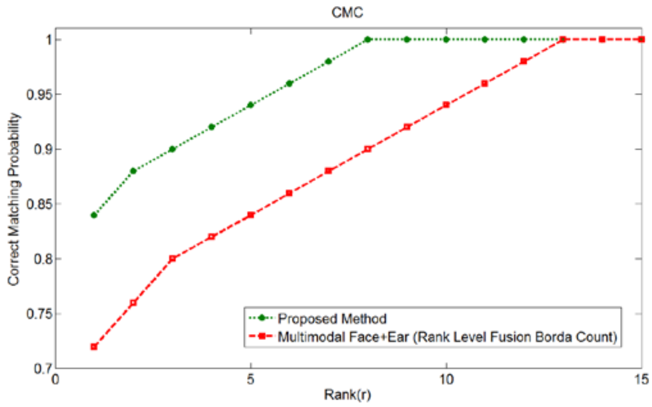

Figure 6. CMC curve for proposed multimodal cancelable biometric template and multimodal rank level fusion of face and ear biometric.

Finally, it has been found that using cancelable biometric template from the unimodal system preserves the interclass and intraclass variability. On the other hand, it can be also seen that multimodal cancelable system improves the performance compared with unimodal biometric system. Thus, the proposed Multimodal Cancelable Biometric System preserves the cancelable property.

Furthermore, if the randomly selected feature indexes were not available, cancelable biometric system would not correctly recognize an individual class. We have tested the system using other randomly selected indexes to split the features. The test was in the same experimental conditions, with modifications in random selection of features. It is found that if the random selection of feature is changed, classifier is unable to recognize the person. This performance ensures cancelability of the template. If those indices of cross folding are available to the attacker, it will be computationally too hard to reproduce the original face or ear template.

V. CONCLUSION

We have presented a novel multimodal cancelable biometric system using rank level fusion. Multi-fold random projection and cross folding are used in the proposed method. For the dimension reduction of templates, PCA is used. Result reported in the paper satisfies cancelable property of a biometric system. Moreover, we applied the technique for the multimodal system that satisfies cancelable property too. The latest result implies that the proposed method can effectively produce cancelable template for multimodal biometric system. More analysis for the cancelability measure can address more challenges of Cancelable Biometric system. However, adopting another biometric trait may improve the cancelability and security of the system. In the future, different rank level fusion methods can be tested to comprehend their influence on the performance.

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