Christian Rathgeb, Christoph Busch, Comparison Score Fusion Towards an Optimal Alignment for Enhancing Cancelable Iris Biometrics, In Proceedings of the 4th International Conference on Emerging Security Technologies (EST13), pp. 51-55, 2013. ©IEEE. The copyright for this contribution is held by IEEE Xplore Digital Library. The original publication is available at http://ieeexplore.ieee.org.

Comparison Score Fusion Towards an Optimal Alignment for Enhancing Cancelable Iris Biometrics

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***Abstract*—Technologies of cancelable biometrics protect biometric data by applying transforms to biometric signals which provide a comparison of biometric templates in the transformed domain. Approaches to cancelable biometrics entail a significant decrease in recognition accuracy, i.e. applied feature transforms highly effect biometric feature extractors and comparators. In the presented work cancelable iris biometric systems operating in image domain are investigated. Sequences of comparison scores obtained during the process of feature alignment are combined in various fusion scenarios. As a result recognition accuracy is significantly improved, eliminating the inevitable decrease in accuracy caused by cancelable transforms, i.e. the proposed approach enables an operation of cancelable iris biometric systems at a high security level.**

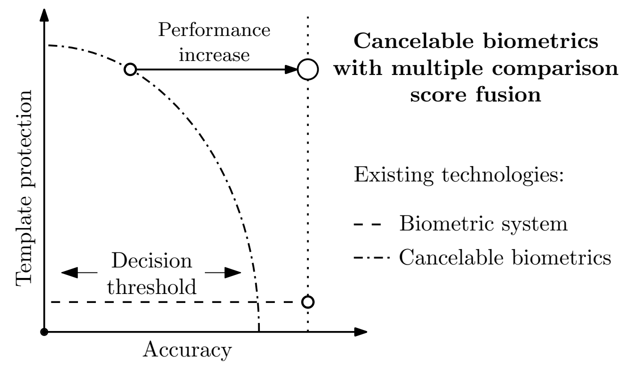


Fig. 1. Unprotected and cancelable biometric system: fusion of multiple scores is targeted at maintaining original accuracy.

I. Introduction

Unprotected storage of biometric data provokes serious privacy threats, e.g. identity theft, cross-matching, or limited renewability. Cancelable biometrics, which offer solution to biometric template protection [1], consist of intentional, repeatable distortions of biometric signals based on transforms which provide a comparison of biometric templates in the transformed domain [2]. The vast majority of published approaches to cancelable biometrics report a significant decrease in recognition performance, since in most cases local neighborhoods of feature elements are obscured and/ or enrolled templates (which have been transformed) are not seen, i.e. alignment can not be performed properly during comparisons [1]. Regarding iris biometrics [3], the majority of recognition algorithms aim at extracting highly discriminative binary templates, i.e. iris-codes, applying the fractional Hamming distance (HD) to calculate (dis-)similarity scores, while potential improvements in comparison procedures are commonly neglected.

The contribution of this work is an estimation and meaningful application of appropriate algorithm-dependent comparison score fusions in order to reduce the inevitable biometric performance decrease caused by cancelable biometric transforms, Fig. 1 depicts this inter-relation. In the presented approach a sequence of comparison scores is obtained during the alignment of biometric templates, i.e. the efficiency of HD-based comparison is retained. The proposed approach is evaluated for a representative cancelable iris recognition system for various parameterizations. Experimental evaluations confirm the soundness of the presented comparison score fusion. This paper is organized as follows: Sect. III summarizes related work. In Sect. III the proposed approach is described in detail. Experimental evaluations are presented in Sect. IV. In Sect. V conclusions are drawn.

II. Related Work

The prior idea of cancelable biometrics has been introduced by Ratha *et al.*in [2]. Based on block permutation and surface-folding the authors generated cancelable templates from pre-aligned fingerprints and facial images. In further work [4], different techniques to create cancelable iris biometrics have been proposed. The authors suggest four different transforms applied in image and feature domain in which iris textures and iris-codes are obscured in a row-wise manner, i.e. adjacency of pixels and bits is maintained along x-axis in image and feature domain, respectively. It is important to note that a row-wise transformation of iris textures or iris-codes, e.g. a row-wise permutation of iris texture stripes, preserves a computational efficient alignment of resulting iris-codes based on circular bit-shifting. In [5] transformations suggested in [2] have been applied to iris biometrics, including a permutation of texture blocks. Significant performance drops have been observed even for a block size of 32×32 pixel which, in case of an invertible permutation, results in a maximum theoretical key space of size $32! \simeq 2^{118}$. Unlinkability studies have demonstrated that in general practical key spaces are much lower than maximum theoretical boundaries [6]. Despite these major contributions other approaches to cancelable iris biometrics have been proposed, e.g. in [7], [8], [9].

Binary iris biometric templates offer two major advantages, compact storage and rapid authentication computing fractional HDs [10]. Template alignment is performed within a single

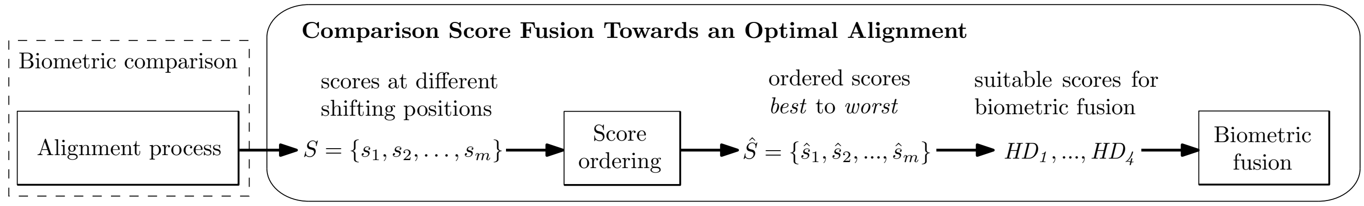


Fig. 2. Comparison score fusion: basic operation mode of the proposed approach, which combines several scores obtained during the feature alignment process.

dimension, applying a circular shift of iris-codes in order to obtain a perfect alignment, i.e. to compensate a certain amount of relative eye-rotation. Traditional iris recognition systems preserve the best match only [3], i.e. the minimum *HD* score, however, there is no evidence, that other computed *HD* scores can not contribute to an improved recognition accuracy. Only a few approaches have demonstrated that more sophisticated biometric comparators significantly improve the overall accuracy of an iris recognition system [11], [12], [13]. In addition, some approaches to biometric fusion in template protection schemes have been proposed, e.g. in [14]. With respect to previous works in the field of cancelable iris biometrics and advanced biometric comparators, this paper represents the very first application of advanced iris biometric comparators to cancelable iris biometrics. It will be demonstrated that by incorporating advanced comparison techniques in particular, a fusion of diverse comparison scores obtained during template alignment, shortcomings of cancelable biometric systems regarding biometric performance can be reduced or even eliminated.

III. Comparison Score Fusion Towards an Optimal Alignment

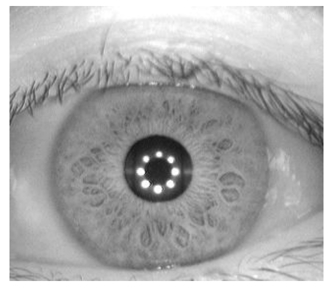
Information fusion in biometrics is an efficient means to enhance the accuracy of a biometric system by employing multiple modalities, instances, sensors, or comparators [15]. Score level fusion enables transparent enhancement of biometric systems by combining the comparison scores of multiple comparators yielding a score set S, which is frequently combined applying sum rule or product rule [16]:

$$S = \{s_1, s_2, \ldots, s_m\}, \qquad s = \sum_{i=1}^{m} s_i \text{ or } s = \prod_{i=1}^{m} s_i. \quad (1)$$

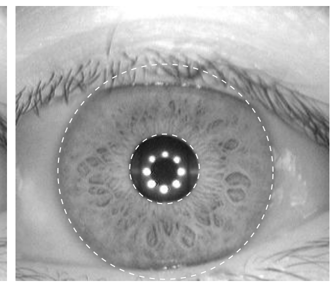
In the proposed comparison score fusion a single-sensor single-algorithm fusion is investigated in which different comparison scores result from *HD*s estimated at diverse shifting positions during alignment. It is important to notice that the considered scenario is rather challenging while it enables a straight forward integration to existing systems without incorporating additional sensors or feature extractors. Furthermore, additional computational effort is minimized since the estimation of involved comparison scores (during the alignment process) is mandatory. Fig. 2 depicts the basic operation mode of the proposed comparison score fusion towards an optimal alignment.

In the first step the score set S is ordered with respect to ascending *HD*s resulting in the score set $\hat{S}$,

$$\hat{S} = \{\hat{s}_1, \hat{s}_2, ..., \hat{s}_m |\ \forall i < j : \hat{s}_i < \hat{s}_j\}. \quad (2)$$



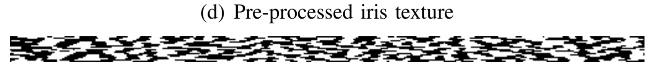
(a) Acquisition



(b) Detection

(c) Iris texture

(d) Pre-processed iris texture



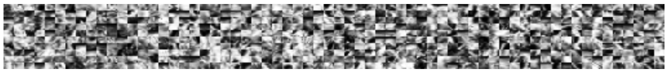
(e) Iris-code of 1-D Log-Gabor filter

(f) Iris-code of Ma *et al.*

Fig. 3. Applied pre-processing and feature extraction algorithms.

Subsequently, based on the ordered set $\hat{S}$, algorithm specific subsets are selected out of four comparison scores. In conducted experiments these comparison scores (which are computed efficiently) where found to be the best suitable ones, applying sum rule and product rule, in order to enhance the accuracy within a single-sensor single-algorithm scenario:

1) $HD_1 := \hat{s}_1$: the best obtained *HD* represents the basis for comparing iris-biometric templates, i.e. the minimum *HD* will be involved at each fusion;
2) $HD_2 := 1 - \hat{s}_m$: in order to estimate the improvement gained during the alignment process, the worst score, is considered as well;
3) $HD_3 := \sum_{i=1}^{n} \hat{s}_i / n$: in addition, the mean comparison score, is calculated.
4) $HD_4 := \hat{s}_2$: the second best score is assumed to "confirm" HD_1, since scores are expected to improve towards an optimal alignment, i.e. in case of genuine comparisons HD_4 should be close to HD_1;



(a) 8×5 block permutation

(b) 16×5 block permutation

(c) 32×5 block permutation

Fig. 4. Cancelable iris textures applying different block sizes and sample permutations for the iris texture of Fig. 3 (d).

IV. Experimental Studies

Experiments are carried out using the CASIA-v3-Interval iris database[1]. At pre-processing the iris of a given sample image is detected, un-wrapped to an enhanced rectangular texture of 512×64 pixel, shown in Fig. 3 (a)-(d) applying the weighted adaptive hough algorithm proposed in [17]. In the feature extraction stage custom implementations of two different iris recognition algorithms are employed in which normalized iris textures are divided into stripes to obtain 10 one-dimensional signals, each one averaged from the pixels of 5 adjacent rows (the upper 512×50 rows are analyzed only). The first feature extraction algorithm resembles Daugman's feature extraction method [10] applying a row-wise convolution with a complex Log-Gabor filter. The second algorithm is based on the feature extraction of Ma *et al.*[18] in which a 1-D wavelet transform is applied to each of the ten 1-D intensity signals and detected minima and maxima from two specific subbands serve as features. Sample iris-codes consisting of 10240 bits are shown in Fig. 3 (e)-(f).

In order to obtain cancelable templates a block permutation is applied to preprocessed iris textures. Since applied feature extraction methods operate on texture stripes of 5 pixel height and normalized iris textures are of length 512, adequate block sizes of 8×5, 16×5, and 32×5 pixel are selected. In Fig. 4 resulting iris textures are depicted for a sample permutation applied to the pre-processed iris texture of Fig. 3 (d). Applied transforms obscure adjacency along x-axis alignment, i.e. transforms are applied at various texture shifts. The suggested target system is found to be representative for generic cancelable biometric systems since increasing security ($\simeq$ decreasing block sizes) decreases accuracy and vice versa. Theoretical key spaces can be easily estimated based on the number of applicable permutations. A block size of 32×5 defines a theoretical key space of (512·50 / 32·5)! = 160! $\simeq 2^{945}$ while a block size of 32×5 defines a theoretical key space of (512·50 / 8·5)! = 640! $\simeq 2^{5048}$. Compared to existing approaches to cancelable iris biometrics, e.g. [4], [5], considered target systems provide reasonable larger theoretical key spaces, i.e. maintaining recognition accuracy turns out to be even more challenging. The resulting trade-off between accuracy and security, operated by chosen block sizes, will be investigated in biometric performance evaluations.

[1]The Center of Biometrics and Security Research, http://www.idealtest.org

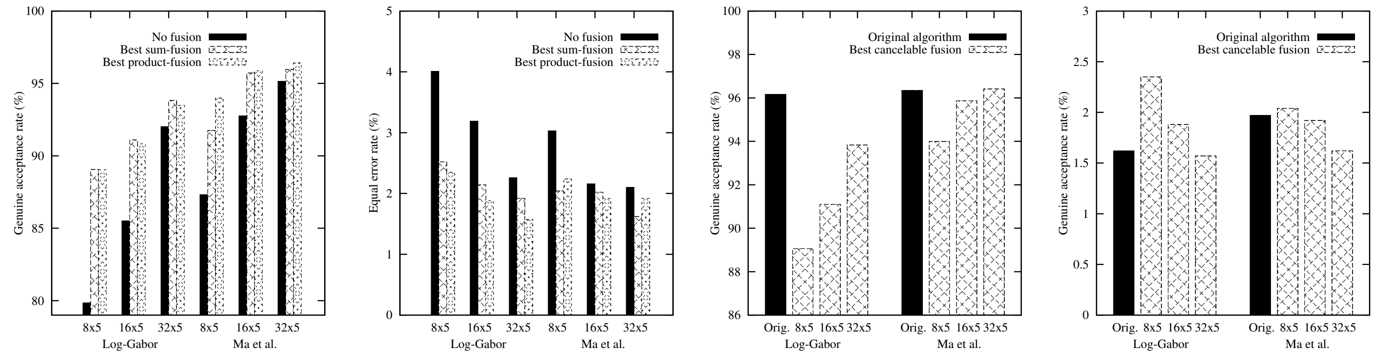
TABLE I. Performance rates (in %) for the Log-Gabor feature extraction (GARs are obtained at FAR=0.01%).

Comparison score				8×5		16×5		32×5	
HD_1	HD_2	HD_3	HD_4	GAR	EER	GAR	EER	GAR	EER
√				79.83	4.01	85.50	3.19	92.02	2.26
+	+			83.22	3.04	86.11	2.24	90.47	1.93
+		+		68.79	4.95	75.96	3.88	85.28	2.88
+			+	79.01	3.94	90.07	2.36	91.48	2.69
+	+	+		85.08	3.56	89.94	2.79	**93.83**	**1.92**
+	+		+	**89.06**	**2.52**	**91.10**	**2.14**	93.57	2.20
+		+	+	74.39	4.94	81.07	3.99	88.06	3.15
+	+	+	+	80.95	3.85	87.09	3.45	92.47	2.59
∗	∗			**89.04**	**2.35**	**90.83**	**1.88**	**93.48**	**1.57**
∗		∗		70.20	5.01	79.21	3.87	86.93	1.77
∗			∗	79.92	4.00	85.39	3.29	90.97	2.59
∗	∗	∗		77.39	3.54	85.25	2.98	93.30	2.35
∗	∗		∗	84.90	3.22	90.25	2.59	93.48	2.02
∗		∗	∗	73.81	4.73	80.37	3.74	89.13	2.85
∗	∗	∗	∗	77.93	3.70	83.28	2.95	92.54	2.37

A. Performance Evaluation

Performance is evaluated in terms of genuine acceptance rate (GAR) at a targeted false acceptance rate (FAR) and equal error rate (EER). Focusing on the described cancelable systems a single random permutation is applied to all subjects, i.e. experiments are carried out in the stolen-token scenario [19] where obtained results are averaged from 100 different random permutations.

At a FAR of 0.01% the original recognition systems based on the Log-Gabor feature extraction and the algorithm of Ma *et al.*obtain GARs of 96.16% and 96.34% yielding in EERs of 1.62% and 1.97%, respectively. These performance rates define the target performance which should be maintained by the cancelable biometric systems. Table I and Table II summarize obtained GARs at FARs of 0.01% and according EERs for the Log-Gabor feature extraction and the algorithm of Ma *et al.*, respectively, for all possible fusion scenarios where "+" indicates sum-rule fusion and "∗" indicates product rule fusion (all scores are weighted equally). Performance rates of original cancelable biometric systems (without comparison score fusion) are summarized in the first line of each table causing significant decrease in biometric performance. By applying the proposed comparison score fusion a significant increase in biometric performance is achieved for both algorithms at almost no additional computational effort. Focusing on the Log-Gabor feature extraction biometric performance is almost maintained for a permutation of 32×5 pixel blocks. For the smaller block sizes the original performance of 96.16% dropped to 85.50% for the HD_1 score. When applying the proposed fusion scheme incorporating HD_1, HD_2 and HD_4 the accuracy is significantly increased to a GAR of 91.10%. Regarding the feature extraction algorithm of Ma *et al.*even better results are obtained, almost retaining biometric performance for block sizes of 32×5 and 16×5 pixels. Again, for a block size of 8×5 pixel significant improvement is yielded, achieving a GAR of 93.99% compared to 87.32%. Best obtained sum-rule fusions (marked bold) appear algorithm-dependent. Improvements, gained by best



(a) GAR (b) EER (c) GAR (d) EER

Fig. 5. Performance rates: (a)-(b) GARs at FAR of 0.01% and EERs of the original cancelable system, best sum- and product-fusion, and (c)-(d) original recognition system compared to the best cancelable systems for different block permutations.

TABLE II. PERFORMANCE RATES (IN %) FOR THE FEATURE EXTRACTION OF MA *et al.*(GARS ARE OBTAINED AT FAR=0.01%).

Comparison score				8×5		16×5		32×5	
HD_1	HD_2	HD_3	HD_4	GAR	EER	GAR	EER	GAR	EER
$\surd$				87.32	3.03	92.76	2.16	95.15	2.10
+	+			89.60	2.04	**95.72**	**2.02**	**95.96**	**1.62**
+		+		74.70	3.89	88.10	3.19	92.65	2.77
+			+	86.24	3.04	90.92	2.83	92.94	2.65
+	+	+		88.73	2.14	94.35	2.64	95.27	2.48
+	+		+	**91.75**	**2.04**	94.73	2.09	95.65	1.97
+		+	+	80.66	3.91	87.16	3.45	90.52	2.44
+	+	+	+	87.81	2.58	92.36	2.85	94.33	2.01
$\ast$	$\ast$			**93.99**	**2.24**	**95.87**	**1.92**	**96.41**	**1.92**
$\ast$		$\ast$		77.24	3.73	88.53	2.82	92.33	2.33
$\ast$			$\ast$	86.29	2.98	91.12	2.52	93.97	2.44
$\ast$	$\ast$	$\ast$		85.90	2.65	93.25	2.39	95.25	2.52
$\ast$	$\ast$		$\ast$	89.71	2.47	94.46	2.28	95.65	2.13
$\ast$		$\ast$	$\ast$	80.42	3.90	87.88	3.11	95.60	2.46
$\ast$	$\ast$	$\ast$	$\ast$	86.62	3.23	90.30	2.48	94.28	2.24

sum-rule and product-rule fusions are depicted in Fig. 5 (a)-(b) showing GARs at the targeted FAR and EERs respectively, for both feature extractors and different cancelable systems. Fig. 5 (c)-(d) compares the best obtained GARs at a FAR of 0.01% and best obtained EERs, respectively, to that of original systems which do not protect templates.

V. CONCLUSION

In the proposed work the inevitable degradation of recognition accuracy caused by cancelable iris biometric systems is overcome through different types of efficient fusions of comparison scores obtained towards an optimal alignment. In experiments significant improvement with respect to biometric performance is achieved for different types of a representative cancelable iris biometric systems. Results, which are obtained for different feature extraction algorithms on a comprehensive dataset, enable an operation of cancelable iris biometrics at significantly higher security levels.

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