PERFORMANCE EVALUATION OF FEATURE SETS OF MINUTIAE QUADRUPLETS

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Abstract

The features proposed in this paper are derived from minutiae quadruplets and are applicable in matching and indexing fingerprint images. In this work nineteen different possibilities of features were explored for indexing and the performances of some of the feature sets were mixed: some giving good performances on certain databases and poor performances on other databases. A final ranking was done and one feature-set was chosen as viable geometrical features for minutiae matching and indexing based on their performances on three Fingerprint Verification Databases (FVC) 2000, 2002 and 2004.

Keywords: fingerprint, quadruplets, minutiae

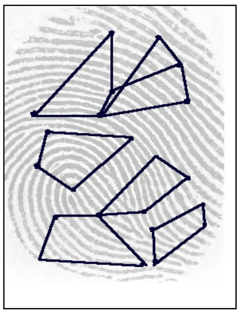

Figure 1: Minutiae Quadruplets in a Fingerprint.

1. Introduction

A minutia is a region of discontinuity or abrupt change in the ridge flow pattern in a fingerprint [1]. A fingerprint is a friction-ridge impression of the epidermal ridges and furrows in a fingertip [2]. A fingerprint could be latent, scanned, plastic, ink or patent. Minutiae quadruplets have been recently proposed for minutiae-based matching and indexing [3]. Minutiae quadruplets are sets of four minutiae points forming many quadrilaterals in a fingerprint as shown in Figure 1.

Minutiae quadruplets give a lot of possibilities of features for matching and indexing. In this research nineteen different feature sets were explored for indexing and the performances of some of the feature sets were mixed: some giving good performances on certain databases and poor performances on other databases. This shows that the evaluation of algorithms on just one or two databases is not sufficient to confirm the performance of techniques as they may be database-dependent. Much work was done to find a feature-set that would have a good performance across three FVC databases of the FVC 2000, 2002 and 2004. One out of nineteen feature-sets was chosen based on the good performances of the features on the three databases.

2. Evaluation of Nineteen Feature Sets

The purpose of the experimentation was to determine which feature sets would effectively index a fingerprint. For a feature set to be adjudged beneficial for indexing or matching, it would possess the following characteristics:

- Be robust [4] and stable
- Be database independent
- Give uniform good performance among all datasets

The nineteen different feature sets were tested on three databases, FVC 2000 DB1, 2002 DB3 and 2004 DB1 [5, 6, 7], to identify which feature sets would give a good performance on all three databases. These three databases, one from each year, were chosen because the datasets of one database vary considerably from the datasets of the other databases. FVC 2000 DB1 and FVC 2002 DB3 are fairly noisy databases and FVC 2004 DB1 database is very noisy. The performance of FVC 2004 database is not expected to equal or compete with the FVC 2000 and 2002 databases. These three different types of datasets give the variety of datasets necessary to judge effectively the performance of a feature set. The experiment was carried out using 200 datasets from one of the two fairly noisy databases and the very noisy database. Feature sets adjudged good using the 200 datasets were ranked using 800 datasets. Table 1 is a table of symbols for the features in a quadruplet, abcd, as shown in Figures 2 to 7.

It would not be possible to illustrate the nineteen feature sets however some of feature sets illustrated cover other feature sets not illustrated. The six feature sets 1, 4, 8a, 10, 17 and 19 are illustrated in Figure 2 through Figure 7.

Feature set 10 is shown in Figure 5 and Feature set 17 is illustrated in Figure 6. Feature set 19 comprising 5 features is illustrated in Figure 7.

Table 1: Table of Symbols for the Features used in a Quadruplet in Figures 2 to 7.

Symbols	**Features explained**
θ_1, θ_2, θ_3, θ_4	Four interior angles
α_1, α_2, α_3, α_4	Four exterior angles
β_1, β_2, β_3, β_4	Sums of three exterior angles. $\beta_1 = \alpha_1+\alpha_2+\alpha_4$ $\beta_2 = \alpha_1+\alpha_2+\alpha_3$ $\beta_3 = \alpha_2+\alpha_3+\alpha_4$ $\beta_4 = \alpha_1+\alpha_3+\alpha_4$
δ_1; δ_2	Two diagonals of a quadruplet
$\text{area}_\text{q}\text{uad}$	Area of quadruplet
area_//gram	Area of inner parallelogram
$\delta p1$; $\delta p2$	Two diagonals of parallelogram
λ	Parallelogram base angle
δ_{ra}	$(\delta_1/\delta_2)\times 50$. i.e. ratio of diagonals scaled by 50
δ_{rb}	$(\delta_1/\delta_2)\times$ area_//gram
osr_ 1a; osr_ 2a	$(\overline{ab}/\overline{cd})\times(\overline{ab}+\overline{cd})$; $(\overline{bc}/\overline{ad})\times(\overline{bc}+\overline{ad})$ i.e. opposite side ratios, each scaled by the sum of lengths of sides
osr_ 1b; osr_ 2b	$(\overline{ab}/\overline{cd})\times\sin(\lambda)$; $(\overline{bc}/\overline{ad})\times\sin(\lambda)$
ε_1; ε_2	$\lambda\times(ab+cd)$; $\lambda\times(bc+ad)$
φ_1; φ_2	$\theta_1-\theta_3; \theta_2-\theta_4$
ph; pb	Parallelogram height; parallelogram breadth
ρ_1; ρ_2	Two perpendicular heights of parallelogram
η	Global feature, $\eta = 100\log 10(\tau\nu)$, where $\tau = \sqrt{\overline{w_1w_2}\cdot\overline{w_1ph_1}} + \sqrt[+]{(\overline{ab}\cdot\overline{bc}\cdot\overline{cdad})}$ and $\nu = \sqrt{\mu} + \sqrt{\overline{w_1w_2}\cdot\overline{w_2w_3}}$ $\mu = \{(s-\overline{ab})(s-\overline{bc})(s-\overline{cd})(s-\overline{ad}) - (\overline{ab}\cdot\overline{bc}\cdot\overline{cd}\cdot\overline{ad})\cos^2(\theta_1+\theta_3)/2\}^{0.5}$ Where s is semi-perimeter of the quadruplet, abcd.

3. Experiments

The experiments were conducted using three of the FVC databases – 2000 DB1, 2002

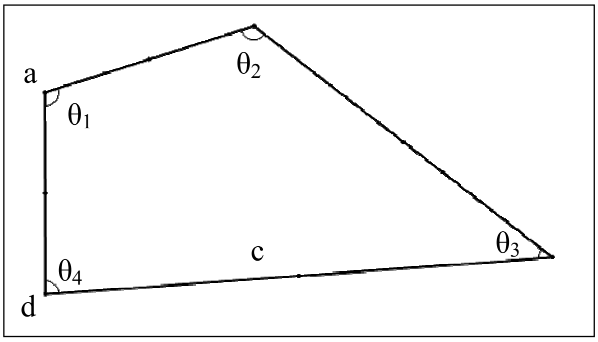

Figure 2: Feature set 1 = $\theta_1,\ \theta_2; \theta_3,\ \theta_4$ comprising 4 features.

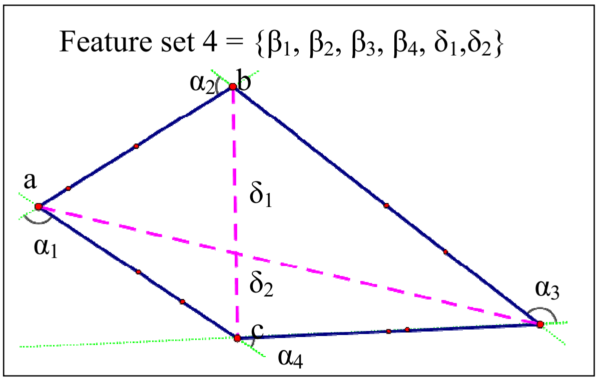

Figure 3: Feature set 4 comprising 6 features namely, $\beta_1,\ \beta_2,\ \beta_3,\ \beta_4,\ \delta_1,\ \delta_2$.

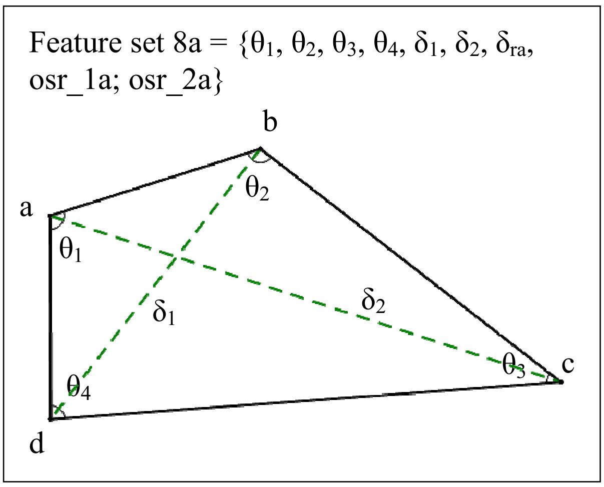

Figure 4: Feature set 8a comprising 9 features namely, $\theta_1,\ \theta_2,\ \theta_3,\ \theta_4,\ \delta_1,\ \delta_2,\ \delta_{ra},\ osr\_1a;\ osr\_2a$.

DB3 and 2004 DB1. 200 datasets were chosen from each database. Features were extracted for the seventeen different quadruplet sets. Hence, the experiments were repeated seventeen times using the proposed feature set in each case. In each experiment, 100 tests were carried out with 100 fingerprints, using the remaining 100 datasets in the database. The hit rates and the overall penetration rates were determined for each feature set. The hit rate is the probability that the genuine fingerprint is retrieved from the database for a given input in a test [8]. Given a database of size, N, and number of tests, T, the overall penetration is the longest penetration for a test in the entire tests. This is otherwise seen as the worst case penetration. The overall penetration rates were determined at hit rates of 20% and 50%.

4. Interpretation of Experimental Results

From the experiments, if a feature set has poor performance in both databases, it is rejected as a feature set beneficial for indexing since the objective is to select feature sets with good performances.

If a feature set has a good performance in one database and poor performance in another database, it is rejected because the feature set is database dependent. Our objective is to select feature sets that give uniform good performance among all datasets.

If a feature set has good performance in both databases, it is selected as a possible feature set for indexing. All such feature sets are again evaluated and ranked using the 800 dataset.

5. Evaluation of Feature Sets based on their Penetration Rates at Hit Rates of 20% and 50%

The feature sets were evaluated based on their penetration rates at hit rates of 20% and 50%. The penetration rate at a hit rate of 20% is the fraction of the database identities retrieved including the genuine fingerprint for 20% of the query fingerprints in the test and likewise the penetration at a hit rate of 50% is the fraction of the database identities retrieved for 50% of the queries in the test. Good performance is characterized by low penetration rates while poor performance is characterized by high penetration rates. The thresholds for good performance, moderate performance and poor performance for the fairly noisy and very-noisy databases are set out as shown in Table 2.

6. Comparison of the Performances of the Feature Sets

Table 3 shows the comparison of the performances of feature sets 1 to 6 on 200 fingerprint images of the FVC 2002 DB3 and 2004 DB1 databases.

From the results in Table 3, feature set 5 is selected because it has good performances in both databases.

Feature sets 7, 8a and 8b are compared on 200 fingerprints of the FVC 2002 DB3 and 2004 DBI databases as shown in Table 4.

From Table 4, these feature sets are not selected for indexing for the reasons given in the comments.

Feature sets 9 to 17 are compared on 200 fingerprints of the FVC 2002 DB3 and 2004 DB1 databases as shown in Table 5.

From the results of Table 5, Feature set 17 is selected because it has uniform good performances in both databases.

Feature set 18 and 19 were tested on 200 images of the FVC 2002 DB3 and FVC 2004 DB1 as shown in Table 6.

No feature sets were selected from the results of Table 6.

From the evaluation of the 19 feature sets, Feature sets 5 and 17 were selected based on their uniform good performance in both FVC databases 2002 DB3 and 2004 DB1. Feature sets 5 and 17 had penetration rates of 1.0% and 0.9% respectively at 20% hit rate and 5.2% and 5.0% respectively at 50% hit rate in DB3 2002. In 2004 DB1, feature sets 5 and 17 had penetration rates of 2.0% and 1.9% respectively at 20% hit rate and 8.0% and 7.0% respectively at 50% hit rate. The two feature sets were ranked by evaluating their performance on all datasets of three databases in order to determine which has the best performance.

Feature sets 5 and 17 were tested on all 800 images of FVC DB1 2000, DB3 2002 and DB1 2004. The performances are compared in Table 7.

7. Discussions

From the evaluation carried out on the three databases in Table 7, feature set 17 outperformed feature set 5 in 2002 DB3 and 2004 DB1 while both had comparable results in DB1 2000. Hence, feature set 17 is selected because it has the best performance.

Feature sets 3, 4, 6, 7, 9, 10, 15 and 16 do not have a uniform performance across all databases and may not be good feature sets. They are affected by the kind of datasets. Feature sets 1, 2, 11, 12, 13, 14 and 19 are rejected because none of them had a good performance on any database. Feature set 5 is a possible quadruplet set because it had good performances across the three databases. Feature sets 8a and 8b did not have a poor performance on any database, though they had a mixture of moderate and good performances, they may be possible feature sets for indexing.

However, feature set 17 had the best performance in all the three databases as shown in Table 5 and Table 7 compared with other 18 feature sets. Feature set 17 (see Figure 6) is therefore proposed as a robust quadruplet feature set for feature matching and indexing.

Feature set 17 was compared to [9, 10] as shown in Table 8. Both approaches used the FVC 2002 database. Boer et al. combined the method of Fingercodes [11] with minutiae triplets in [10]. Minutiae quadruplets has the best performance since the penetration rates

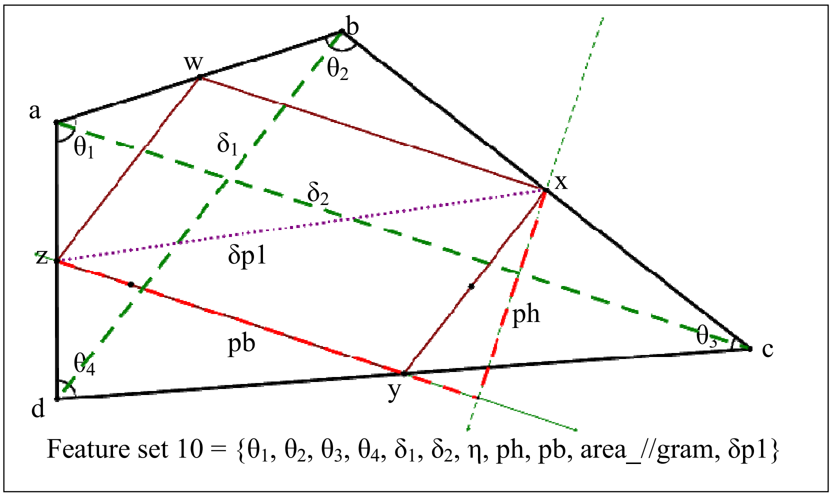

Figure 5: Feature set 10 comprising 11 features namely, θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, η, ph, pb, $area\_//gram$, $\delta p1$.

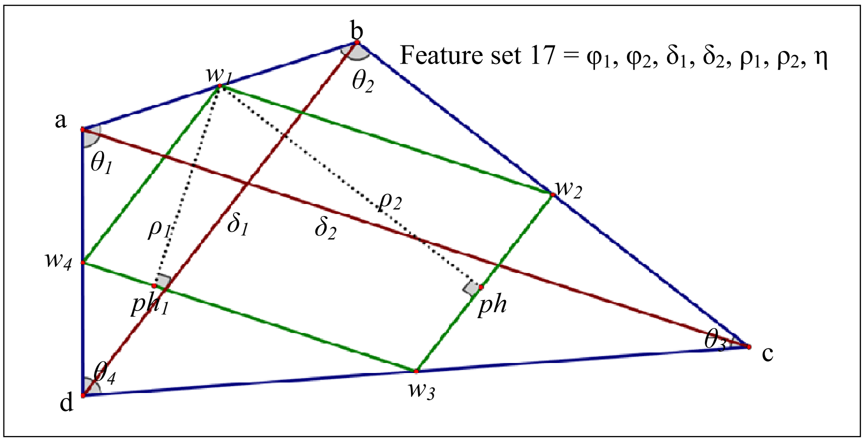

Figure 6: Feature set 17 comprising 7 features namely, φ_1, φ_2, δ_1, δ_2, ρ_1, ρ_2, η.

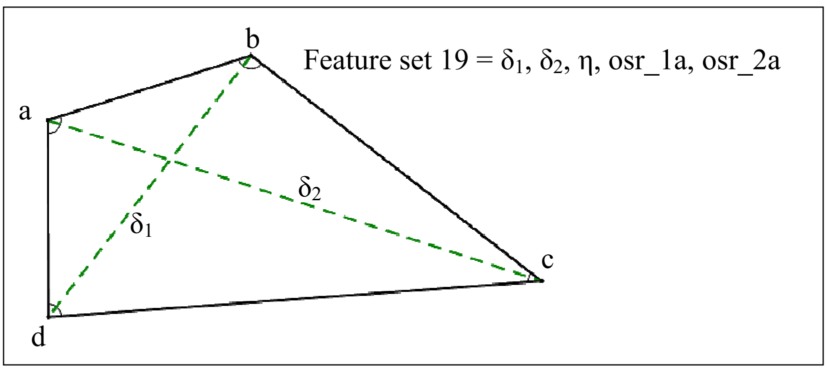

Figure 7: Feature set 19 comprising 5 features namely, δ_1, δ_2, η, osr_1a, osr_2a.

Table 2: Threshold of penetrations for good, moderate and poor performances at 20% and 50% hit rates for the fairly noisy and very noisy databases in Tables 3 to 7.

	Penetration rates at 20% and 50% hit rates respectively for	
Performances	Fairly noisy databases	Very noisy databases
Good	<= 1.3%; <= 5.5%	<= 2.5%; <= 8.5%
Moderate	(> 1.3 & <= 1.8)%; (> 1.3 & <= 7.5)%	(> 2.5 & <= 3.0)%; (> 8.5 & <= 10.0)%
Poor	> 1.8%; > 7.5%	> 3.0%; > 10.0%

Table 3: Comparison of the performances of feature sets 1 to 6 on 200 fingerprint images of the FVC 2002 DB3 and 2004 DB1 databases.

Set No	Feature sets and number of features	Penetration rates at 20% and 50% hit rates respectively. (%)		Comments
		DB3-02	DB1-04	
1	θ_1, θ_2, θ_3, θ_4 (4)	1.7 ; 8.0	4.0; 11.0	Set 1 has poor performances in both databases and is hence rejected.
2	β_1, β_2, β_3, β_4 (4)	2; 8.5	4.0; 13.4	Feature set 2 has poor performances in both databases and is rejected.
3	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2 (6)	1.2; 5.5	2.1; 9.0	Feature sets 3 and 4 have good performances in DB3 2002 but moderate performances in DB1 2004. Feature set 5 has good performances in both databases. Feature set 6 has a moderate performance in DB3-02 but a good performance in DB1-04. Feature set 5 is selected as a possible feature set for indexing. Feature sets 3, 4 and 6 are rejected because we have a feature set that has good performances in both databases.
4	β_1, β_2, β_3, β_4, δ_1, δ_2 (6)	1.0; 5.5	2.2; 9.0	
5	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, η (7)	1.0; 5.2	2.0; 8.0	
6	β_1, β_2, β_3, β_4, δ_1, δ_2, ν (7)	1.5; 5.8	2.2; 8.0	

Table 4: Comparison of the performances of feature sets 7, 8a and 8b on 200 fingerprints of the FVC 2002 DB3 and 2004 DB1 databases.

Set No	Feature sets and number of features	Penetration rates at 20% and 50% hit rates respectively. (%)		Comments
		DB3-02	DB1-04	
7	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, $area\_//gram$ (7)	2.0; 6.5	2.2; 7.0	Feature set 7 has poor performance in DB3-02 but good performance in DB1 2004 and is rejected because feature set is database dependent.
8a	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, δ_{ra}, osr_1a; osr_2a (9)	1.4; 6.5	2.5; 10.0	Feature set 8a has moderate performances in DB3 2002 and DB1-04 and is hence rejected.
8b	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, δ_{rb}, osr_1b; osr_2b (9)	1.5; 6.5	2.5; 7.0	Set 8b has a moderate performance in DB3 2002 and good in DB1-04. It could be used as a feature set for indexing but because we have better features sets it is rejected.

Table 5: Comparison of the performances of feature sets 9 to 17 on 200 fingerprint images of the FVC 2002 DB3 and 2004 DB1 databases.

Set No	Feature sets and number of features	Penetration rates at 20% and 50% hit rates respectively. (%)		Comments
		DB3-02	DB1-04	
9	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, η, $area\_//gram$ (8)	2.0; 6.2	2.5; 7.3	Performance of set 9 is good in DB1 2004 but poor in DB3 2002 and is hence rejected as an indexing feature set. Set 10 has moderate performances in both databases and is rejected. Feature set 11 has a moderate performance in DB3-02 but poor in DB1-04 and is rejected. Feature set 12 has poor performance in DB3-02 and moderate performance in DB1-04 and is rejected because features are database-dependent.
10	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, η, ph, pb, $area\_//gram$, $\delta p1$ (11)	1.6; 5.1	1.5; 9.0	
11	δ_1, δ_2, η, $\delta p1$, ph, pb (6)	1.5; 6.0	2.1; 9.0	
12	δ_1, δ_2, η, $\delta p1$, ph, pb, $area\_//gram$ (7)	1.9; 6.1	2.0; 10.0	
13	δ_1, δ_2, η, $\delta p1$, ph, pb, osr_1a; osr_2a (8)	4.0; 15.0	4.0; 17	Performances of feature sets 13 and 14 are poor and are rejected.
14	η, osr_1a; osr_2a (3)	2.0; 11.0	3.0; 12	
15	δ_1, δ_2, $\delta p1$, ρ_1, ρ_2, ε_1, ε_2 (8)	1.7; 6.0	1.8; 8.0	Sets 15 and 16 have moderate performances in DB3-02 and good performances in DB1-04 and are rejected because performance is not sufficiently uniform.
16	δ_1, δ_2, η, $\delta p1$, ph, pb, λ (7)	1.5; 7.0	2.0; 7.0	
17	δ_1, δ_2, η, ρ_1, ρ_2, φ_1, φ_2 (7)	0.9; 5.0	1.9; 7.0	Feature set 17 has a very good performance in DB3-02 and a good performance in DB1-04. It has the best performance out of the 19 feature sets for a dataset of 200 images. It is selected as a feature set for indexing.

Table 6: Feature set 18 and 19 tested on 200 datasets of the FVC 2002 DB3 and FVC 2004 DB1.

Set No	Feature sets and number of features	Penetration rates at 20% and 50% hit rates respectively. (%)		Comments
		DB3-02	DB1-04	
18	η, $\delta p1$, ph, pb, φ_1, φ_2 (6)	1.0, 5.5	2.5, 9.0	Feature set 18 has a good performance on DB3 2002 but moderate in DB1 2004 and is rejected because performance is not sufficiently uniform.
19	δ_1, δ_2, η, osr_1a; osr_2a (5)	1.7, 8.0	3.0; 11.5	Performance of feature set 19 is poor on both databases and is hence rejected.

Table 7: Feature sets 1, 5 and 17 tested on all 800 fingerprint images of the FVC DB1 2000, DB3 2002 and DB1 2004 set A.

Set No	Feature sets and number of features	Penetration rates at 20% and 50% hit rates respectively. (%)			Comments
		DB1-00	DB3-02	DB1-04	
5	θ_1, θ_2, θ_3, θ_4, δ_1, δ_2, η (7)	1.4; 4.0	1.5; 6.0	2.0; 7.75	Feature set 5 had a good performance in the three databases.
17	δ_1, δ_2, η, ρ_1, ρ_2, φ_1, φ_2 (7)	1.0; 4.75	1.2; 5.0	2.0; 7.0	Feature set 17 had the best performance in the three databases.

Table 8: Comparison of Minutiae Quadruplet (Set 17) with Chikkerur et al. [9] and Boer et al. [10] in experiments carried out with FVC 2002.

Technique	Penetration rates at	
	20% hit rate	50% hit rate
Minutiae quadruplets (Set 17)	1.20	5.00
Localized Texture Features [9]	2.25	8.09
Multiple Features [10]	2.70	7.75

at hit rates of 20% and 50% respectively are the least – 1.20% and 5.00%.

8. Conclusion

The goal of this paper was to analyze some proposed feature sets of minutiae quadruplets and determine which sets are possible features for fingerprint matching and indexing. Experiments were carried out on nineteen quadruplet feature sets by evaluating their performances on three Fingerprint verification Competition (FVC) databases 2000, 2002 and 2004. The feature set that had the best performance is proposed as a viable feature set for matching and indexing fingerprints.

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