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S. RASSOMAKHIN, O. MELKOZEROVA, O. NARIEZHNII

V. N. Karazin Kharkiv National University, Ukraine

THE METHOD OF VICINITY MINUTIAE DECOMPOSITION WITH HIGHER LEVEL GRAPHS FOR FINGERPRINT VERIFICATION

*The **subject matter** of the paper is the development of fingerprint local structures based on the new method of the minutia vicinity decomposition (MVD) for the solution to the task of fingerprint verification. It is an essential task because it is produced attempts to introduce biometric technology in different areas of social and state life: criminology, access control system, mobile device applications, banking. The **goal** is to develop real number vectors that can respond to criteria for biometric template protection schemes such as irreversibility with the corresponding accuracy of equal error rate (EER). The **problem** to be solved is the problem of accuracy in the case of verification because there are false minutiae, disappearing of truth minutiae and there are also linear and angular deformations. The **method** is the new method of MVD that used the level of graphs with many a point from 7 to 3. This scheme of decomposition is shown in this paper; such a variant of decomposition is never used in science articles. The following **results** were obtained: description of a new method for fingerprint verification. The new metric for creating vectors of real numbers were suggested – a minimal path for points in the graphs. Also, the algorithm for finding out minimal paths for points was proposed in the graphs because the classic algorithm has a problem in some cases with many points being 6. These problems are crossing and excluding arcs are in the path. The way of sorting out such problems was suggested and examples are given for several points are 20. Results of false rejection rate (FRR), false acceptance rate (FAR), EER are shown in the paper. In this paper, the level of EER is 33 % with full search. 78400 false and 1400 true tests were conducted. The method does not use such metrics as distances and angles, which are used in the classical method of MVD and will be used in future papers. This result is shown for total coincidences of real number, not a similarity that it is used at verifications. It is a good result in this case because the result from the method index-of-max is 40 %.*

Keywords: *fingerprint verification; minutia vicinity decomposition; false rejection rate; false acceptance rate; equal error rate; the minimal path for points in the graph.*

Introduction

At present, there are attempts to introduce biometric technology for identification and verification in different informational protection services [1, 2], such as criminology, access control, and identification systems, e-commerce systems, general informational security systems (authorization and access to the information system), voting and electronic digital signature systems, electronic payments, state identification projects (border crossing, visas), etc. Fingerprint recognition is a problem that has been studied for 40 years and it is still an open issue.

It should be noted that despite huge number of published articles no one service (protocol) has been developed that used biometric data and responded all requirements of integrity, authenticity, accessibility, and information systems confidentiality and services [3, 4].

Minutia cylinder codes [5] are minutiae based fingerprint description that used 3D cylinder structures. Each cylinder is a local structure and contains data about spatial and directional contributions of minutia. It should be noted that this method is very hard for implementation. Vectors of real numbers is quite massive and the full process of verification can take 24 hours. This method has an advantage is high accuracy, EER might be 2…8 % for different data bases.

In the paper [6, 7] authors propose a ranking-based sensitive hashing for biometric protection that used so-called index-of max (IoM) for biometric fingerprint protection. This method IoM used cylinder structures [5], multiplication of matrixes, and choice by the maximum. This method is enough good for voice verification (EER 7 %), but results are not good enough for fingerprints. EER is about 40 %. The speed of verification after writing templates is quite high.

In [8] the authors proposed the method which is called MVD for obtaining a vector of real numbers. This method has advantages: simplicity and fast fingerprint verification. The method allows constructing local structures. Also, it provides stability to linear and angular deformations and resistance to appear false minutiae and disappear truth ones as in [5]. The scheme of decomposition is shown in Figures 1, 2. But this method also has a disadvantage - low accuracy. Figure 2 is shown the decomposition of the real fingerprint from a database.

Method MVD was criticized in the paper [9] because an attacker can create a fake fingerprint with a set of artificial minutia vicinity from the compromised template. Matcher simply can compare the features of minutiae triangles directly without knowledge of minutiae locations and orientations.

It is suggested binarization of vectors decreases the speed of verification. The task of binarization is solved in many papers like [5, 10]. But after using these methods the quality of vectors is decreased.

The MVD method with higher-level graphs solves all problems that were mentioned above: accuracy, time of verification, and the criteria of security. The goal of the research is to develop real number vectors that can respond to criteria for biometric template protection schemes such as irreversibility with the corresponding accuracy of equal error rate (EER).

1. Schema of MVD with higher level graphs

According to [11] minutia template is $T=\{m_1, m_2, \dots m_n\}$. Each minutia is a triplet $m=\{x_m, y_m, \theta_m\}$, where x_m and y_m is a minutia location or coordinate, θ_m – is a minutia direction, n – amount of minutiae in template.

The paper suggests the method based on MVD [8], but it uses the higher level graphs. It is not possible to be completely sure about existence or absence of any minutia. For this reason in the paper proposed the new schema of decomposition for each minutia from template of fingerprint (Figure 3). The schema is described below with the real example. The method consists of local structures construction [5]. Local structures are the structures connected with local coordinate systems of each minutia.

In the Figure 4, a and Figure 4, b there is the vicinity that consists of 8 minutiae, these are the nearest minutiae. Coordinates of these minutiae are seeing in the Figure 4, b. The number of possible variants of decomposition can be calculated with using well known formula:

$$C_n^k = \frac{n!}{k!(n-k)!}, \qquad (1)$$

where n – amount of minutiae from vicinity;

k – amount of minutiae are supposed really exist in the vicinity.

According to (1) the number of possible decompositions is calculated in the Table 1. If the number of exist minutiae are 7 and 1 minutia is false, it might be 8 possible variants of decompositions.

The number of false minutiae can be 2, so the number of possible decompositions are 28. The total amount of variants are 218. Also the schema of decomposition is shown in the Figure 5.

Table 1

Possible decompositions of minutia vicinity

The number of vicinity minutiae	The number of probably true minutiae	The number of probably false minutiae	The number of combinations
8	7	1	8
8	6	2	28
8	5	3	56
8	4	4	70
8	3	5	56
		Σ	218

In the last case triangles are considered, there are 56 variants. Preparation of such variants is not a problem and has a solution to any amount of points.

In the Table 2 and 3 examples of these decompositions with coordinates that were chosen in the Figure 3 are shown. The variants with only one and two probably false minutiae were presented. As a result were obtained the graphs with number of point from 7 to 3. Some of these graphs are shown in the Figure 4. For creating of these graphs was used basic well known algorithm finding shortest distance between points. This algorithm was described below in this paper with changes for providing absence of crossing arcs of graphs.

2. The basic algorithm to find out shortest distance between points

Properties of solution of salesman task such as resistance to points mixing, linear and angular transformations, were studied in [12]. These properties make it possible to use for biometric identification.

In this paper algorithm was used to sort out the salesman task [13]:

1. Preparation of matrix of mutual distances $n \times n$.
2. Finding minimal values of distances in rows.
3. Subtraction minimal values of distances from corresponding rows.
4. Finding minimal values of distances in each column.
5. Subtraction minimal values of distances from corresponding columns.
6. As the result, a minimum one zero element has to be in each row and corresponding to each zero element there is the constant of bringing, this is the sum of minimal values in the corresponding row and column.
7. Choice of bringing constant with the biggest values.
8. Include the corresponding arc (i, j) in the path.
9. Exclude some arc from matrix by including the sign ∞. The excluding this arc is the complicated

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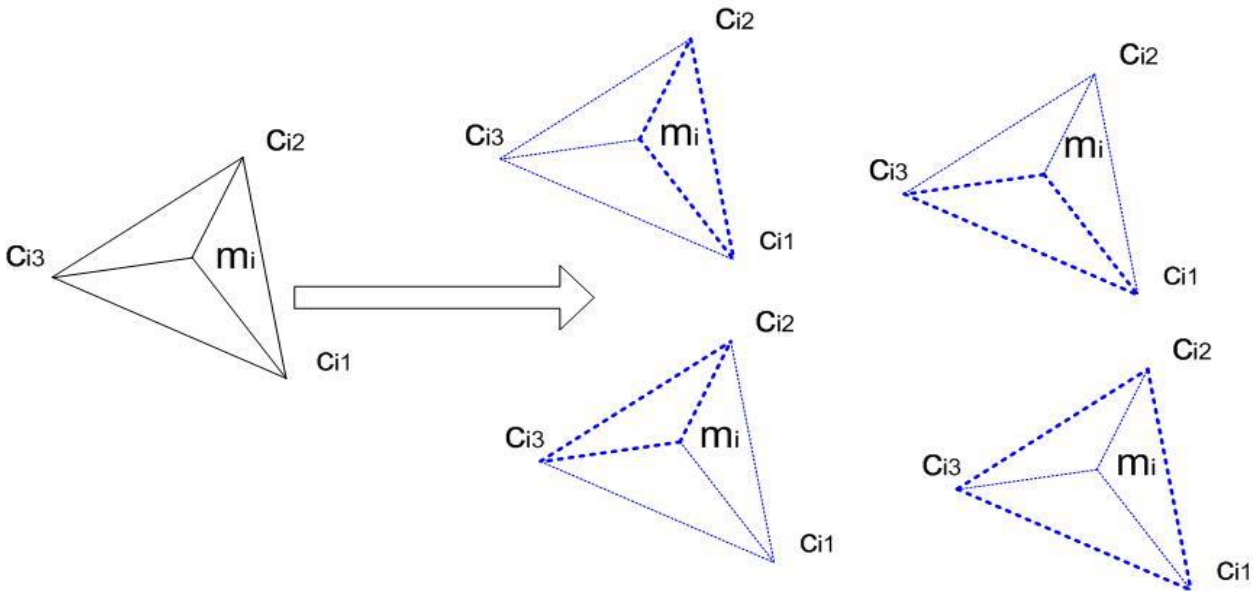


Fig. 1. Vicinity of minutia m_i, scheme of vicinity minutia decomposition

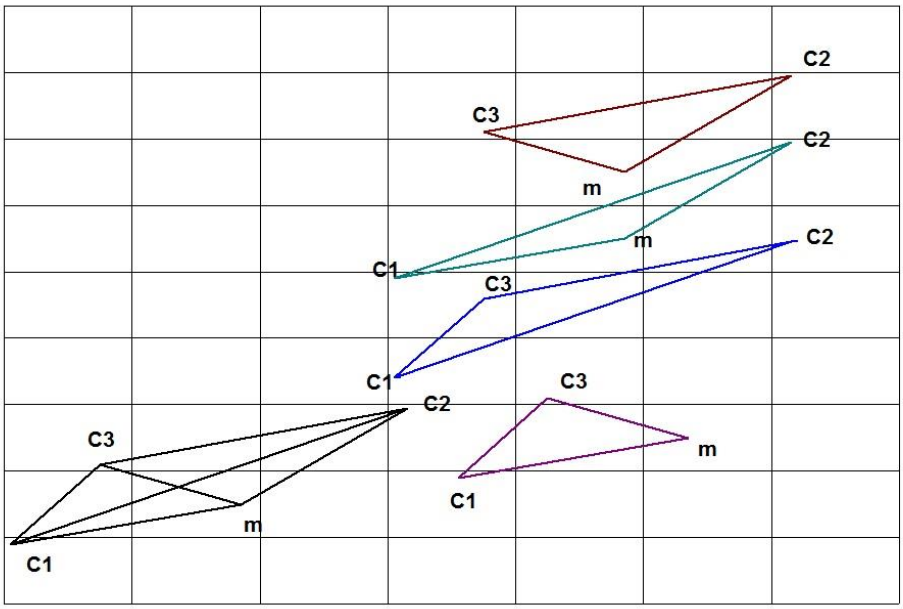
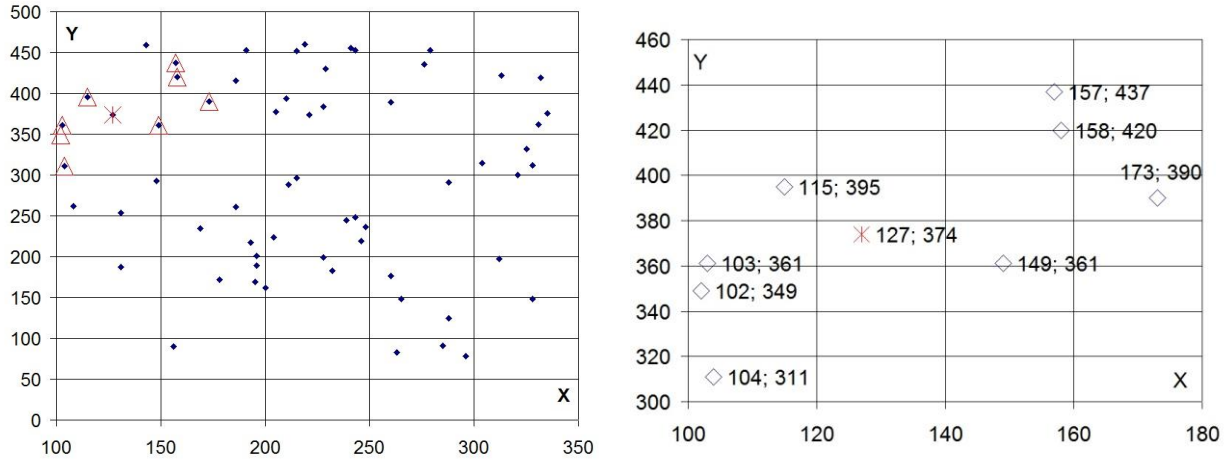


Fig. 2. Vicinity minutia decomposition on the real fingerprint according to [8]

	8 variants of decomposition	28 variants of decomposition	56 variants of decomposition	70 variants of decomposition	56 variants of decomposition
m1	Graphs with 7 true minutiae	Graphs with 6 true minutiae	Graphs with 5 true minutiae	Graphs with 4 true minutiae	Graphs with 3 true minutiae
m2	Graphs with 7 true minutiae	Graphs with 6 true minutiae	Graphs with 5 true minutiae	Graphs with 4 true minutiae	Graphs with 3 true minutiae
	……...		……...		
mn	Graphs with 7 true minutiae	Graphs with 6 true minutiae	Graphs with 5 true minutiae	Graphs with 4 true minutiae	Graphs with 3 true minutiae

Fig. 3. Vicinity minutiae decomposition according to the MVD with higher level graphs method



a b

Fig. 4. Vicinity of minutia with coordinates (127, 374): a – all fingerprint; b – the vicinity of the minutia

Table 2

Variants of minutia decompositions from 8 points

№	Possible variants of decompositions, one minutia is false							Path
0	0	1	2	3	4	5	6	
X	115	149	103	102	173	158	104	274,3
Y	395	361	361	349	390	420	311	
1	0	1	2	3	4	5	7	
X	115	149	103	102	173	158,	157,	244,2
Y	395	361	361	349	390	420	437	
2	0	1	2	3	4	6	7	
X	115	149	103	102	173	104	157	300,1
Y	395	361	361	349	390	311	437	
3	0	1	2	3	5	6	7	
X	115	149	103	102	158	104	157	289,5
Y	395	361	361	349	420	311	437	
4	0	1	2	4	5	6	7	
X	115	149	103	173	158	104	157	300,9
Y	395	361	361	390	420	311	437	
5	0	1	3	4	5	6	7	
X	115	149	102	173	158	104,	157	307,2
Y	395	361	349	390	420	311	437	
6	0	2	3	4	5	6	7	
X	115	103	102	173	158	104	157	301
Y	395	361	349	390	420	311	437	
7	1	2	3	4	5	6	7	
X	149	103	102	173	158	104,	157	302,3
Y	361	361	349	390	420	311	437	

process. It was discussed in the [14] and shown examples in Tables 4.

10. Cross out i-row and j-column from the matrix.

11. Repeat 2-10 until the matrix has not size $(n-2)^x(n-2)$.

12. The last two arcs are needed to choose from the elements, where the excluding is not put.

13. Looking throw the path to find out crossing arcs.

14. Deleting the crossing arcs by changing two points on the arcs, example of this was shown bellow (Table 5 and Figure 6) [14].

Table 3

Variants of minutia decompositions from 8 points

№	Possible variants of decompositions, two minutiae are false						Path
0	0	1	2	3	4	5	
X	115	149	103	102	173	158	217,5
Y	395	361	361	349	390	420	
1	0	1	2	3	4	6	
X	115	149	103	102	173	104	249,3
Y	395	361	361	349	390	311	
2	0	1	2	3	4	7	
X	115	149	103	102	173	157	243,3
Y	395	361	361	349	390	437	
3	0	1	2	3	5	6	
X	115	149	103	102	158	104	262,8
Y	395	361	361	349	420	311	
4	0	1	2	3	5	7	
X	115	149	103	102	158	157	232,7
Y	395	361	361	349	420	437	
…	…	…	…	…	…	…	..
26	1	3	4	5	6	7	
X	149	102	173	158	104	157	297,3
Y	361	349	390	420	311	437	
27	2	3	4	5	6	7	
X	103	102	173	158	104	157	298,8
Y	361	349	390	420	311	437	

Table 4

Example for excluding arcs from the path

Iteration number	Arcs from path	Arcs for excluding
0	14; 15	15; 14
1	16; 18	18; 16
2	3; 11	11; 3
3	11; 5	3; 5
4	4; 6	6; 4
5	6; 16	4; 18

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3. Results of experiments

In this research each minutia is represented by the vector. The amount of the closest minutiae is 10 was used for creating feature vectors. The size of the vectors was n*56, where n – the number of minutiae in templates. Restriction on the radius of vicinity is up to 60.

78400 false and 1400 true tests were carried out with using database from [15]. Each template in database is represented by p1_p2, where the first number p1 is the number of person; the second number p2 is the position of the finger. For example, all numbers of coincidence were given in the Table 6 for both 0_0 and 0_1 templates.

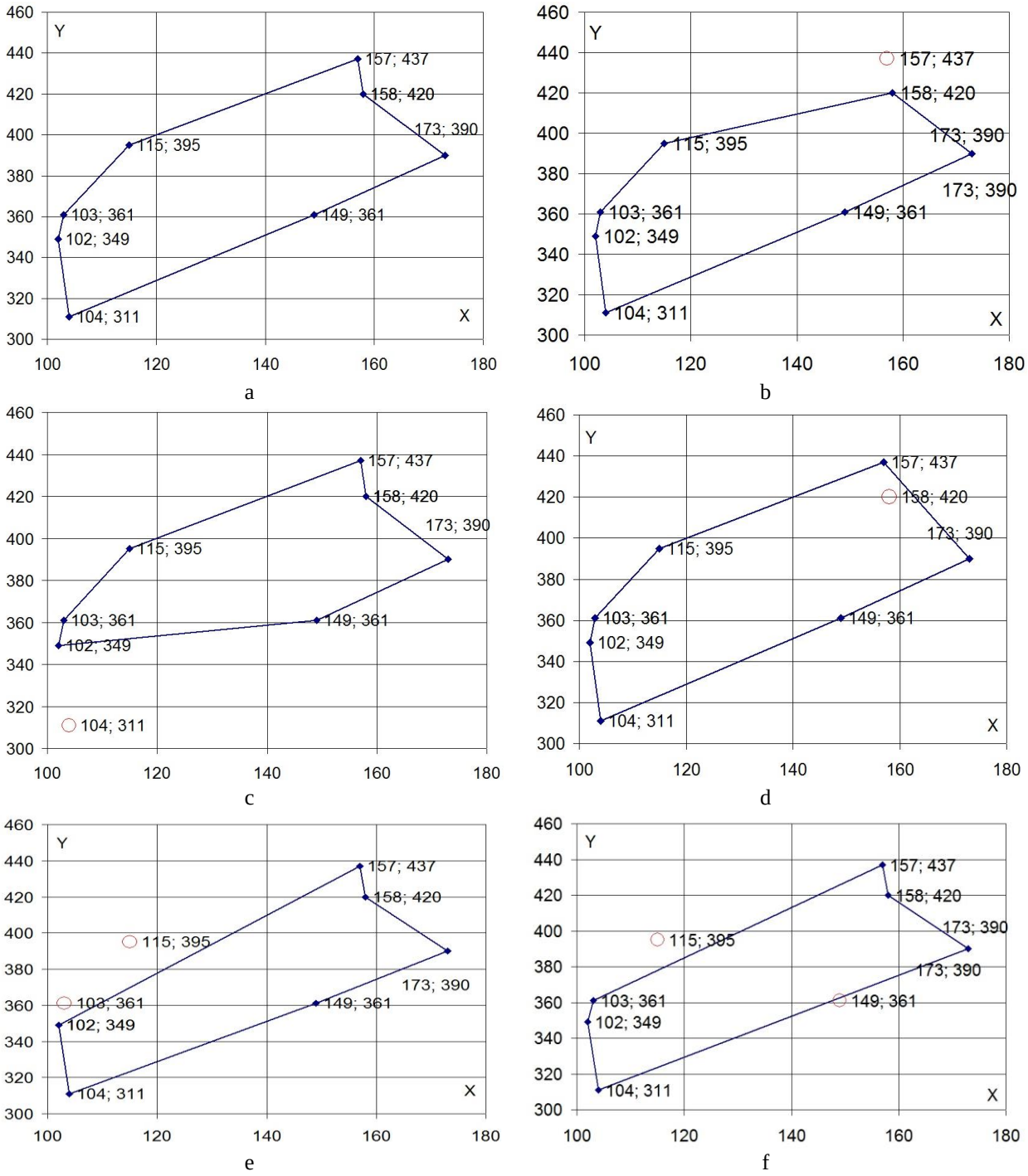
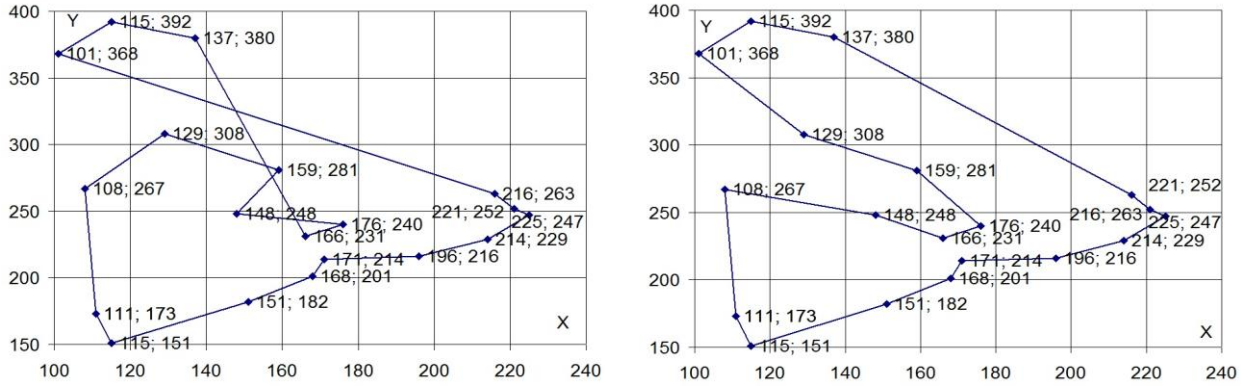


Fig. 5. Graphic representations of some variants of decompositions from Tables 2 and 3: a – all minutiae are true, graph with 8 points; b – one minutia with coordinates (157, 437) is false, graph with 7 points; c – one minutia with coordinates (104,311) is false, graph with 7 points; d – one minutia with coordinates (158,420) is false, graph with 7 points; e – two minutiae with coordinates (103,361) and (115,395) are false, graph with 6 points, 26th variants from Table 3; f – two minutiae with coordinates (149,361) and (115,395) are false, graph with 6 points, 27th variants from Table 3

Table 5

Solutions from the basic algorithm and optimal solution X''''''_i, Y''''''_i

Point from the path	X'	Y'	X''	Y''	X'''	Y'''	X''''	Y''''	X'''''	Y'''''	X''''''	Y''''''
0	111	173	111	173	111	173	111	173	111	173	111	173
1	115	151	115	151	115	151	115	151	115	151	115	151
2	151	182	151	182	151	182	151	182	151	182	151	182
3	168	201	168	201	168	201	168	201	168	201	168	201
4	171	214	171	214	171	214	171	214	171	214	171	214
5	196	216	196	216	196	216	196	216	196	216	196	216
6	214	229	214	229	214	229	214	229	214	229	214	229
7	225	247	225	247	225	247	225	247	225	247	225	247
8	221	252	221	252	221	252	221	252	221	252	221	252
9	216	263	216	263	216	263	216	263	216	263	216	263
10	101	368	137	380	137	380	137	380	137	380	137	380
11	115	392	115	392	115	392	115	392	115	392	115	392
12	137	380	101	368	101	368	101	368	101	368	101	368
13	166	231	166	231	176	240	148	248	129	308	129	308
14	176	240	176	240	166	231	166	231	166	231	159	281
15	148	248	148	248	148	248	176	240	176	240	176	240
16	159	281	159	281	159	281	159	281	159	281	166	231
17	129	308	129	308	129	308	129	308	148	248	148	248
18	108	267	108	267	108	267	108	267	108	267	108	267
19	111	173	111	173	111	173	111	173	111	173	111	173



a b

Fig. 6. Excluding crossing arcs from the optimal solution:
a – solution X'_i, Y'; b – the fifth iteration of deleting crossing arcs X''''''_i, Y''''''_i

Table 6

Numbers from experiment 0_0 and 0_1

Total amount of numbers is 272 for experiment 0_0 and 0_1
354; 299; 349; 231; 314; 262; 394; 325; 328; 368; 306; 317; 343; 373; 373; 352; 352; 448; 284; 371; 308; 371; 288; 243; 303; 220; 263; 194; 194; 279; 302; 216; 303; 237; 325; 319; 285; 375; 319; 323; 250; 295; 312; 314; 218; 381; 296; 296; 286; 286; 270; 325; 271; 238; 287; 287; 314; 266; 336; 301; 255; 375; 378; 378; 316; 254; 327; 333; 299;273; 231; 305; 253; 350; 326; 324; 225; 314; 291;338; 264; 299; 288; 270; 287; 282; 282; 347; 369; 337; 313; 310; 352; 353;357;320;297;280;325;311;253;271;324; 404; 306; 228; 263; 310; 351; 315; 315; 234; 234; 370; 322; 234; 296; 331;365;351;337; 303; 341; 346; 365; 260;322; 301; 242;335;254;345; 302; 327; 302;387; 282;314; 277; 273; 340; 273; 293; 293; 350; 385; 221; 301; 396; 263; 324; 318; 330; 401; 330; 343; 286; 286; 328; 240; 381; 369; 292; 292; 292; 292; 250; 375; 271; 196; 242; 276

There are 272 coincidences as also it is shown in the Table 6. Comparisons of existing methods of verifications are shown in the Table 7. Also some other results for true and false experiments are shown in Table 8. Considering the experiment 0_0 and 0_1, the result is 272 coincidences as in Table 8. In the Figure 7 FAR, FRR and EER are presented. EER is 33 %.

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Table 7

Comparisons of existing methods of verifications

Method	Reference	Time for template writing	Time for full verification	EER, %	Algorithm for verification
MCC	[5]	37 minutes	24 hours	2-8 %	Based on similarity
MCC+IOM	[5, 6, 7]	37+15 minutes	1 hour	40 % for fingerprint, 7-8 % for voice	Full coincidences
MVD	[8, 7]	17 minutes	35 minutes	23 %	Based on similarity, vulnerability according [7]
MVD with higher level graphs	Our paper	1 hours	30 minutes	33 %	Full coincidences

To decrease EER the future research will use vectors which consist of features as in [8]:

$$u_r = (s_{r1}, \Delta o_{r1}, \alpha_{r1}, s_{r2}, \Delta o_{r2}, \alpha_{r2}, s_{r3}, \Delta o_{r3}, \alpha_{r3}), \quad (2)$$

where s_{r1}, s_{r2}, s_{r3} denote the length of the three side of a triangle; r=1, …, 4 corresponding to Figure 1; α_{r1}, α_{r2}, α_{r3} – represent the internal angles; o_{r1}, o_{r2}, o_{r3} are the orientations for minutiae of the triangle. First results of addition verification are shown in the Table 9, 10, Figure 8, a and Figure 8, b. This research was carried out on the templates 0_0 and 0_1 from [15].

Table 8

Values of number for full coincidences in the templates

Values of metric for false tests			Values of metric for true tests		
92	0_0	4_4	172	0_0	0_1
77	0_0	4_5	176	0_0	0_2
113	0_0	4_6	246	0_0	0_3
146	0_0	4_7	262	0_0	0_4
135	0_0	5_0	253	0_0	0_5
190	0_0	5_1	282	0_0	0_6
151	0_0	5_2	267	0_0	0_7
96	0_0	5_3	210	0_1	0_2
140	0_0	5_4	222	0_1	0_3
86	0_0	5_5	200	0_1	0_4
112	0_0	5_6	202	0_1	0_5
125	0_0	5_7	201	0_1	0_6

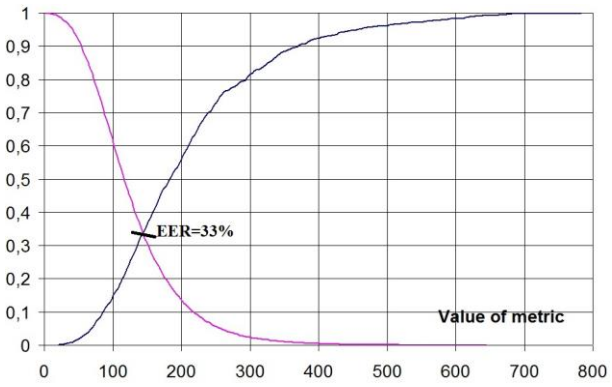
Conclusions

In the research the solution for verification task of fingerprint was suggested. Our solution has advantages (Table 7):

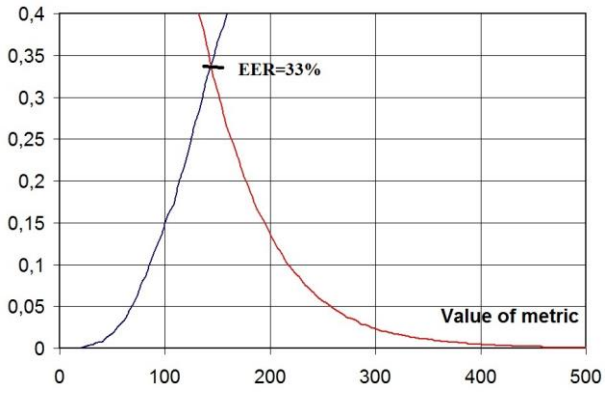
- high speed of extracting the vectors of real values, because of changing the algorithm of finding minimal distances,

- high speed of matching templates of real vectors in compare with cylinder codes in [9].

The solution has disadvantages such as low accuracy for some tests, but it can be improved by adding features, such as angles and distances of which consist our graphs [8]. And it has to be noticed that in such program finding parameters and testing are required a huge amount of time. EER=33 %. This result is not as good as in [5], but matching of templates was carried out for total coincidences of real number, not a similarity that is used at verifications. This is better result than in [6], because the result from the method index-of-max is 40 %.



a



b

Fig. 7. FRR pink and red curves, FAR – blue curve, EER =33%: a – full chart; b - enlarged part of chart

Table 9

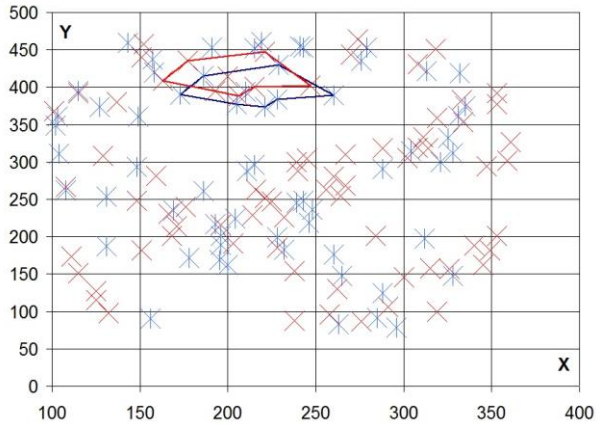
Addition verification with using distances

№	Path	s_{ri}						
0_0	222	51	45	33	32	29	15	14
0_1	220	51	45	34	32	28	16	12

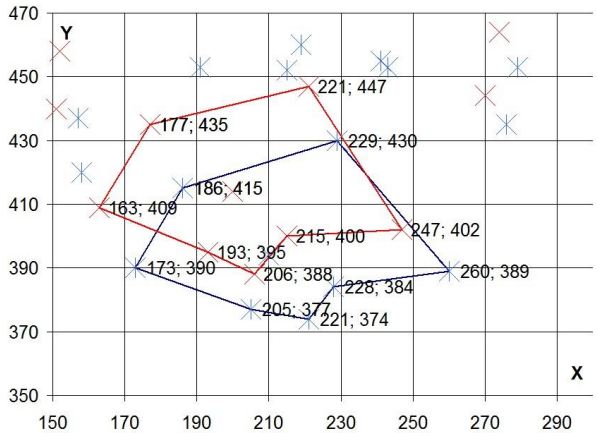
Table 10

Coordinates of contours for templates 0_0 and 0_1

0_0		0_1	
X	Y	X	Y
177	435	186	415
163	409	173	390
193	395	205	377
206	388	221	374
215	400	228	384
247	402	260	389
221	447	229	430
177	435	186	415



a



b

Fig. 8. Demonstration of addition verification for the future research; red color for the template 0_0 and blue color for the template 0_1: a – full chart; b – enlarged part of chart

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МЕТОД ДЕКОМПОЗИЦІЇ ОКОЛИЦЬ МІНУЦІЙ З ВИКОРИСТАННЯМ ГРАФІВ БІЛЬШОГО ПОРЯДКУ ДЛЯ ВЕРИФІКАЦІЇ ВІДБИТКІВ ПАЛЬЦІВ

С. Г. Рассомахін, О. М. Мелкозьорова, О. П. Нарежній

Предмет навчання статті – розробка локальних структур відбитків пальців, який засновується на методі декомпозиції околиць мінуцій для вирішення задачі верифікації відбитків пальців. Це дуже важлива задача, тому що призводяться спроби введення біометричних технологій у різні області соціального та державного життя. Мета полягає у розробці векторів дійсних чисел, які можуть відповідати критеріям до схеми біометричного захисту, таким як незворотність з відповідною точністю рівня еквівалентної помилки (EER). Проблема, яка полягає рішенню – це проблема відповідної точності при верифікації, тому що є помилкові мінуціїї, мінуції, які дописуються, лінійні та кутові деформації. Метод використовує удосконалений метод MVD, він використовує графи з кількістю точок від 7 до 3. Цю схему декомпозиції наведено у статті, такий варіант не було розглянуто у наукових статтях раніше. Було отримано наступні результати: опис нового методу для верифікації відбитків пальців. Ми запропонували нову метрику для побудови векторів – мінімальну відстань між точками у графах. У статті також наведено удосконалений алгоритм для пошуку мінімальної відстані, тому що класичний алгоритм має проблеми у деяких випадках з кількістю точок від 6. Ці проблеми: це дуги, які перетинаються та виключення дуг з маршруту. Ми запропоновуємо шлях вирішення цієї проблеми та надаємо приклад з кількістю точок, яка дорівнює 20. Результати рівня помилкової відмови (FRR), рівня помилкового прийняття (FAR), EER є у статті. Ми провели 78400 помилкових та 1400 дійсних випробувань. Можна сформулювати наступні висновки: рівень EER дорівнює 33 % при повному переборі при тестуванні. Це не найкращі результаті у світі, але при наповнені векторів дійсних чисел ми не використовували відстані між мінуціями та кути, які використовуються у класичному методі MVD. У наступних дослідженнях ми будемо використовувати ці метрики додатково. Також треба визначити, що результати наведено для повного збігу чисел, а не для схожості векторів, як це застосовується при верифікації. Це досить непоганий результат, тому що результат при застосування методу за найбільшим індексом становить близько 40 %.

Ключові слова: верифікація відбитків пальців; декомпозиція околиць мінуцій; рівень помилкової відмови; рівень помилкового прийняття; рівень еквівалентної помилки; мінімальна відстань у графі.

МЕТОД ДЕКОМПОЗИЦИИ ОКРЕСТНОСТЕЙ МИНУЦИЙ С ИСПОЛЬЗОВАНИЕМ ГРАФОВ БОЛЬШЕГО ПОРЯДКА ДЛЯ ВЕРИФИКАЦИИ ОТПЕЧАТКОВ ПАЛЬЦЕВ

С. Г. Рассомахин, О. М. Мелкозерова, О. П. Нарежний

Предметом изучения статьи является разработка локальных структур отпечатков пальцев, который основывается на методе декомпозиции окрестностей минуций для решения задачи верификации отпечатков пальцев. Это очень важная задача, потому что производятся попытки введения биометрических технологий в различные области социальной и государственной жизни. Цель исследования состоит в разработке векторов действительных чисел, которые могут соответствовать критериям схемы биометрической защиты, таким как необратимость с соответствующей точностью уровня равной ошибки (EER). Проблема, которая подлежит решению - это проблема соответствующей точности при верификации, так как существуют ложные минуциии, минуции, которые дописываются, линейные и угловые деформации. Метод использует усовершенствованный метод MVD, он использует графы с количеством точек от 7 до 3. Схема декомпозиции приведена в статье, такой вариант не был рассмотрен в научных статьях ранее. Были

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получены следующие результаты: описание нового метода для верификации отпечатков пальцев. Мы предложили новую метрику для построения векторов - минимальное расстояние между точками в графах. В статье также приведены усовершенствованный алгоритм для поиска минимального расстояния, так как классический алгоритм имеет проблемы в некоторых случаях с количеством точек от 6. Эти проблемы: это дуги, которые пересекаются и исключения дуг из маршрута. Мы предложили путь решения этой проблемы и привели пример с количеством точек, равной 20. Результаты уровня ложного отказа (FRR), уровня ложного доступа (FAR), эквивалентная ошибка (EER) показаны в статье. Мы провели 78400 ложных и 1400 действительных испытаний. Можно сформулировать следующие выводы: уровень EER равен 33 % при полном переборе при тестировании. Это не лучшие результаты в мире, но при наполнении векторов действительных чисел мы не использовали расстояния между минуциями и углы, которые используются в классическом методе MVD. В последующих исследованиях мы будем использовать эти метрики дополнительно. Также надо обозначить, что результаты приведены для полного совпадения чисел, а не для сходства векторов, как это применяется при верификации. Это довольно неплохой результат, потому что результат при применении метода по максимальному индексу составляет около 40 %.

Ключевые слова: верификация отпечатков пальцев; декомпозиция окрестностей минуций; уровень ложного отказа; уровень ложного доступа; уровень эквивалентной ошибки; минимальное расстояние в графе.

Рассомахін Сергій Геннадійович – д-р техн. наук, зав. каф. безпеки інформаційних систем і технологій, Харківський національний університет імені В. Н. Каразіна, Харків, Україна.

Мелкозьорова Ольга Михайлівна – канд. техн. наук, доц. каф. безпеки інформаційних систем і технологій, Харківський національний університет імені В. Н. Каразіна, Харків, Україна.

Нарежній Олексій Павлович – канд. техн. наук, доц. каф. безпеки інформаційних систем і технологій, Харківський національний університет імені В. Н. Каразіна, Харків, Україна.

Sergiy Rassomakhin – PhD, doctor of technical science, professor, head of department of information systems and technologies security V. N. Karazin Kharkiv National University, Kharkiv, Ukraine,
e-mail: rassomakhin@karazin.ua, ORCID: 0000-0003-1394-3588, Scopus Author ID: 6602387161.

Olha Melkozerova – PhD, associate professor of department of information systems and technologies security V. N. Karazin Kharkiv National University, Kharkiv, Ukraine,
e-mail: olha.melkozerova@karazin.ua, ORCID: 0000-0002-1134-2925.

Oleksii Nariezhnii – PhD, associate professor of department of information systems and technologies security V. N. Karazin Kharkiv National University, Kharkiv, Ukraine,
e-mail: o.nariezhnii@karazin.ua, ORCID: 0000-0003-4321-0510, Scopus Author ID: 57201777102.