FVC2004: Third Fingerprint Verification Competition

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Abstract. A new technology evaluation of fingerprint verification algorithms has been organized following the approach of the previous FVC2000 and FVC2002 evaluations, with the aim of tracking the quickly evolving state-of-the-art of fingerprint recognition systems. Three sensors have been used for data collection, including a solid state sweeping sensor, and two optical sensors of different characteristics. The competition included a new category dedicated to "light" systems, characterized by limited computational and storage resources. This paper summarizes the main activities of the FVC2004 organization and provides a first overview of the evaluation. Results will be further elaborated and officially presented at the International Conference on Biometric Authentication (Hong Kong) on July 2004.

1 Introduction

FVC2004 is the third international Fingerprint Verification Competition, a technology evaluation [1] of fingerprint recognition algorithms open to companies, academic research groups and independent developers. Organization of FVC2004 started in April 2003 and the final evaluations were conducted in January-March 2004 at the University of Bologna, Italy. 67 algorithms were evaluated: each algorithm, provided in the form of a binary executable program compliant with precise input/output specifications, was tested on four new fingerprint databases, previously unseen by the participants. This initiative follows FVC2000 [5], [2] and FVC2002 [6], [3], the first two international Fingerprint Verification Competitions, which were organized by the authors in the years 2000 and 2002 with results presented at the 15th ICPR and the 16th ICPR, respectively. The first two competitions received great attention from both academic and commercial organizations. Several research groups started using FVC2000 and FVC2002 datasets for their experimentations and some companies, which initially did not participate in the competitions, requested the organizers to measure their performance against the FVC2000 and/or the FVC2002 benchmark.

Table 1 compares the first two competitions from a general point of view, highlighting the main differences. Beginning with FVC2002, to increase the number of companies and therefore to provide a more complete panorama of the state-of-the-art, the participants were allowed to participate anonymously. We have continued with this option in FVC2004.

The rest of this paper describes FVC2004: section 2 explains the organization of the event, section 3 the collection of the databases, section 4 the test protocol and the performance indicators measured, and section 5 reports some results; finally section 6 draws some conclusions.

Table 1. The first two Fingerprint Verification Competitions

	FVC2000	**FVC2002**
Call for participation	November, 1999	October, 2001
Registration deadline	March 1st, 2000	January 10th, 2002
Submission deadline	June 1st, 2000	March 1st, 2002
Evaluation period	July–August, 2000	April–July, 2002
Notes	Anonymous part. not allowed	Anonymous part. allowed
Registered participants	25 (15 withdrew)	48 (19 withdrew)
Algorithms evaluated	11	31
Presentation of the results	15th ICPR Barcelona, September 2000	16th ICPR Quebec City, August 2002
Databases	4 (set A: 100x8, set B: 10x8)	4 (set A: 100x8, set B: 10x8)
DB1	Optical (KeyTronic)	Optical (Identix)
DB2	Capacitive (ST Microelectronics)	Optical (Biometrika)
DB3	Optical (Identicator Technology)	Capacitive (Precise Biometrics)
DB4	Synthetic (SFinGe v2.0)	Synthetic (SFinGe v2.51)
DB availability	DVD accompanying “Handbook of Fingerprint Recognition” [1]	
Website	http://bias.csr.unibo.it/fvc2000 (more than 41,000 accesses)	http://bias.csr.unibo.it/fvc2002 (more than 40,000 accesses)
HW/SW used for running the evaluation	Pentium III (450 MHz) Windows NT FVC Test suite v1.0	Pentium III (933 MHz) Windows 2000 FVC Test suite v1.2

2 FVC2004 organization

Starting in April 2003 with the creation of the FVC2004 web site [4], we extensively publicized this event. All companies and research groups in the field known to us were invited to participate in the contest. All the participants in the past editions were also informed of the new evaluation. FVC2004 was also announced through mailing lists and biometric-related magazines. Four new databases were collected using three commercially available scanners and the synthetic generator SFinGe [1], [7] (see section 3). A representative subset of each database (sets B, see section 3) was made

available to the participants for algorithm tuning to accommodate the image size and the variability of the fingerprints in the databases.

Two different sub-competitions (Open category and "Light" category) were organized using the same databases. Each participant was allowed to submit one algorithm in each category. The "light" category is intended for algorithms characterized by low computing needs, limited memory usage and small template size (see section 4).

By October 15th, 2003 (the deadline for registration), we had received 110 registrations, far more than our expectation. All the registered participants received the training subsets and detailed instructions for algorithm submission. By November 30th, 2003 (the deadline for submission) we had received a total of 69 algorithms from 46 participants: since two algorithms were not admitted due to unrecoverable incompatibility problems with FVC protocol, the final number of algorithms was 67 (41 competing in the Open category, 26 in the Light category). Once all the executables were submitted, feedback was sent to the participants by providing them the results of their algorithms over training subset B (the same data set they had previously been given) to allow them verify that run-time problems were not occurring on our side (In such cases, participants were allowed to submit updated versions of their algorithms).

At the time this paper is being written, the evaluation has been concluded and each participant has been informed of its individual results. Section 5 presents an overview of the results that will be further elaborated and published on the FVC2004 web site by April 15. Results are presented here in section 5 in anonymous form, since participants have until April 13 to decide whether or not to disclose their identities.

3 Database collection

Four databases constitute the FVC2004 benchmark. Three different scanners and the SFinGE synthetic generator [1], [7] were used to collect fingerprints (see Table 2). Figure 1 shows an image for each database, at the same scale factor.

Table 2. Scanners/technologies used for collecting the databases

	Technology	**Image**	**Resolution**
DB1	Optical Sensor (CrossMatch V300)	640×480	500 dpi
DB2	Optical Sensor (Digital Persona U.are.U 4000)	328×364	500 dpi
DB3	Thermal Sweeping Sensor (Atmel FingerChip)	300×480	512 dpi
DB4	Synthetic Generator (SFinGe v3.0)	288×384	About 500 dpi

A total of ninety students (24 years old on the average) enrolled in the Computer Science degree program at the University of Bologna kindly agreed to act as volunteers for providing fingerprints:

- volunteers were randomly partitioned into three groups of 30 persons; each group was associated to a DB and therefore to a different fingerprint scanner;

- each volunteer was invited to present him/herself at the collection place in three distinct sessions, with at least two weeks time separating each session;
- forefinger and middle finger of both the hands (four fingers total) of each volunteer were acquired by interleaving the acquisition of the different fingers to maximize differences in finger placement;
- no efforts were made to control image quality and the sensor platens were not systematically cleaned;
- at each session, four impressions were acquired of each of the four fingers of each volunteer;
- during the second session, individuals were requested to exaggerate skin distortion (impressions 1 and 2) and rotation (3 and 4) of the finger;
- during the third session, fingers were dried (impressions 1 and 2) and moistened (3 and 4).

At the end of the data collection, we had gathered for each database a total of 120 fingers and 12 impressions per finger (1440 impressions) using 30 volunteers. As in previous editions, the size of each database to be used in the test was established as 110 fingers, 8 impressions per finger (880 impressions); collecting some additional data gave us a margin in case of collection/labeling errors.

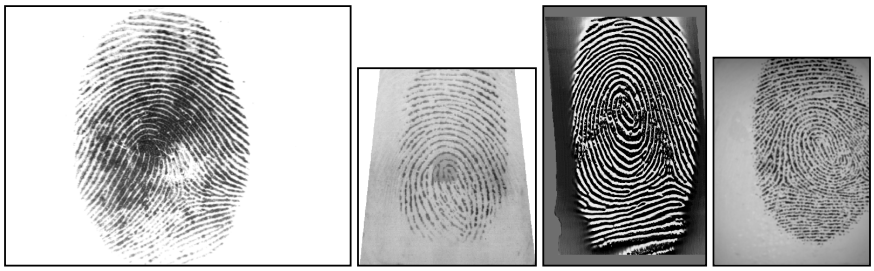

Fig. 1. One fingerprint image from each database, at the same scale factor

4 Test protocol and performance evaluation

The protocol defining the format for the submitted algorithms was given in FVC2000 and remained unchanged throughout FVC2002 and FVC2004.

Each participant was required to submit two executable programs in the form of "win32 console applications". These executables take the input from command-line arguments and append the output to a text file. The input includes a database-specific configuration file. In fact, participants are allowed to submit a distinct configuration file for each database in order to adjust the algorithm's internal parameters (e.g. according to the different sizes of the images). Configuration files are text files or binary files and their I/O is the responsibility of the participant's code; these files can also contain pre-computed data to save time during enrollment and matching.

In the Open category, for practical testing reasons, the maximum response time of the algorithms was limited to 10 seconds for enrollment and 5 seconds for matching. No other limits were imposed in the Open category.

In the Light category, in order to create a benchmark for algorithms of light architectures, the following limits were imposed:

- maximum time for enrollment: 0.5 seconds;
- maximum time for matching: 0.3 seconds;
- maximum template size: 2 KBytes;
- maximum amount of memory allocated: 4 MBytes.

The evaluation (for both categories) was executed under Windows XP Professional O.S. on AMD Athlon 1600+ (1.41 GHz) PCs.

Each algorithm was tested by performing, for each database, the following matching attempts:

- *genuine recognition attempts*: the template of each impression was matched against the remaining impressions of the same finger, but avoiding symmetric matches (i.e. if the template of impression *j* was matched against impression *k*, template *k* was not matched against impression *j*);
- *impostor recognition attempts*: the template of the first impression of each finger was matched against the first impressions of the remaining fingers, but avoiding symmetric matches.

Then, for each database:

- a total of 700 enrollments were performed (the enrollment of the last impression of any finger did not need to be performed);
- if all the enrollments were correctly performed (no enrollment failures), the total number of genuine and impostor matching attempts was 2800 and 4950, respectively.

For each database and for each algorithm, the following performance indicators were measured and reported:

- genuine and impostor score histograms,
- FMR and FNMR graph and ROC graph,
- Failure To Enroll Rate and Failure To Match Rate,
- Equal Error Rate (EER), FMR100, FMR1000, ZeroFMR and ZeroFNMR,
- average match time and average enroll time,
- maximum memory allocated for enrollment and for match [*New in FVC2004*],
- average and maximum template size [*New in FVC2004*].

FMR (False Match Rate) and FNMR (False Non-Match Rate) are often referred as FAR (False Acceptance Rate) and FRR (False Rejection Rate) respectively, but the FAR/FRR notation is misleading in some applications. For example, in a welfare benefits system, which uses fingerprint identification to prevent multiple enrollments under false identity, the system "falsely accepts" an applicant if his/her fingerprint is "falsely not matched"; similarly, a "false match" causes a "false rejection". Consequently, in this paper we use the application neutral terminology "False Match" and "False Non-Match" rates. ZeroFMR is given as the lowest FNMR at which no False Matches occur and ZeroFNMR as the lowest FMR at which no False Non-Matches

occur. FMR100 and FMR1000, are the values of FNMR for FMR=1/100 and 1/1000, respectively. These measures are useful to characterize the accuracy of fingerprint-based systems, which are often operated far from the EER point using thresholds which reduce FMR at the cost of higher FNMR. FVC2004 introduces indicators measuring the amount of memory required by the algorithms and the template size. The indicators are reported for both the categories, although they are particularly interesting for the Light category.

5 Results

Due to the lack of space, only a small part of the results are reported here. Figure 2 shows ROC graphs on the first database for both Open and Light categories. Tables 3 and 4 give the average results over the four databases.

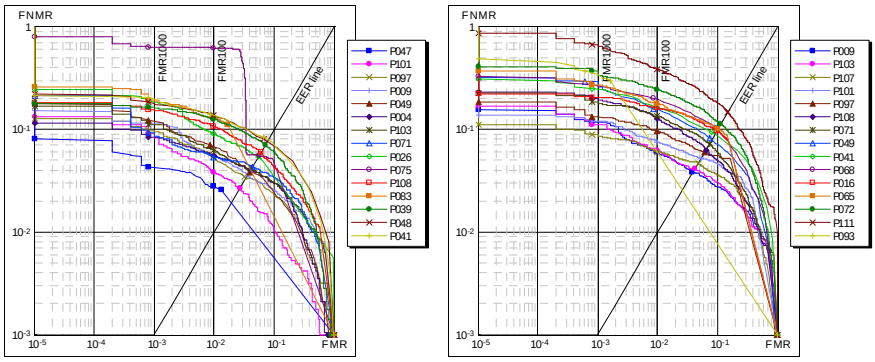

Fig. 2. ROC curves on DB1 (only top 15 algorithms are shown): Open category (on the left), Light category (on the right)

Table 3. Open category: average results over the four databases, sorted by average EER (top ten algorithms)

Algorithm	Avg EER (%)	Avg FMR100 (%)	Avg FMR1000 (%)	Avg ZeroFMR (%)	Avg REJ_{ENROLL} (%)	Avg REJ_{MATCH} (%)	Avg Enroll Time (sec)	Avg Match Time (sec)	Avg Model Size (KB)	Max Model Size (KB)	Max Enroll Mem (KB)	Max Match Mem (KB)
P101	2.07	2.54	4.70	6.21	0.00	0.00	0.08	1.48	24.0	31.5	3204	7752
P047	2.10	2.96	4.61	6.59	0.00	0.00	2.07	2.07	1.3	2.8	5080	5796
P071	2.30	2.73	5.10	10.01	0.00	0.01	0.35	0.67	16.4	31.4	5872	9800
P004	2.45	3.27	5.63	7.34	0.00	0.00	0.69	0.71	2.0	3.8	7012	7032
P039	2.90	4.57	7.44	32.13	0.00	0.00	1.01	1.19	3.1	4.2	4192	4276
P097	3.13	4.49	7.30	11.85	0.04	0.02	0.47	0.51	14.9	28.1	5564	5780
P049	3.24	5.56	9.25	12.62	0.00	0.00	0.34	0.38	0.5	1.2	2472	2496
P009	3.31	4.93	8.32	11.63	0.00	0.00	0.25	0.24	1.3	2.9	2828	2860

P113	3.71	6.07	8.76	11.29	0.00	0.00	0.45	0.48	49.2	93.2	11936	12260
P068	4.03	6.87	11.08	15.68	0.00	0.00	0.43	0.47	7.9	7.9	4468	4456

Table 4. Light category: average results over the four databases, sorted by average EER (top ten algorithms)

Algorithm	Avg EER (%)	Avg FMR100 (%)	Avg FMR1000 (%)	Avg ZeroFMR (%)	Avg REJ_{ENROLL} (%)	Avg REJ_{MATCH} (%)	Avg Enroll Time (sec)	Avg Match Time (sec)	Avg Model Size (KB)	Max Model Size (KB)	Max Enroll Mem (KB)	Max Match Mem (KB)
P009	3.51	5.21	8.71	12.38	0.00	0.00	0.25	0.22	1.2	2.0	2844	2568
P107	3.69	4.68	6.65	8.75	0.00	0.00	0.13	0.13	0.2	0.6	1788	1800
P108	3.96	6.54	10.64	13.12	0.04	0.05	0.23	0.23	1.6	1.6	1952	1976
P101	4.29	6.02	8.91	10.57	0.00	0.00	0.09	0.17	1.1	1.2	2228	3044
P103	4.33	6.66	9.97	13.64	0.00	0.00	0.13	0.14	1.2	2.0	3572	3668
P097	4.86	6.96	10.21	13.12	0.00	0.00	0.19	0.19	2.0	2.0	2100	2108
P071	4.91	8.11	11.44	16.16	0.25	0.18	0.19	0.18	1.2	1.7	2552	2424
P016	5.26	7.68	10.46	13.93	0.00	0.00	0.17	0.19	1.4	2.0	2240	3004
P068	5.29	9.85	15.22	20.18	0.00	0.00	0.16	0.18	2.0	2.0	3448	3428
P049	5.64	10.55	17.13	24.12	0.00	0.00	0.12	0.14	0.5	0.9	1956	1980

6 Conclusions

The third Fingerprint Verification Competition attracted a very high number of participants: 67 algorithms were finally submitted and evaluated. The organization of the event and the evaluation of all the algorithms required more resources and time then expected. Due to time constraints, results presented in this paper are only an initial overview; detailed results and elaborated statistics will be published by April 15 in the FVC2004 web site and discussed at ICBA 2004, where FVC2004 results will be officially presented in a special session together with other technology evaluations on face and signature recognition.

References

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