# TECHNOLOGY EVALUATIONS OF FINGERPRINT-BASED BIOMETRIC SYSTEMS

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**ABSTRACT**

Independent and reliable evaluation of the advances in fingerprint recognition is extremely important for several reasons: 1) to give governments, organizations and to every potential user a clear panorama of the potentiality and current limits of this technology; 2) to compare and rank different solutions (academic and commercial); 3) to provide unambiguous benchmarks/protocols to researchers to track their advances. This paper discusses the fingerprint evaluation campaigns organized in the recent years, focusing on the three editions of the Fingerprint Verification Competition (FVC).

## 1. Introduction

A large number of applications are demanding effective and reliable biometric solutions. Fingerprints proved to be one of the best biometric modalities thanks to their distinctiveness, stability and accessibility (low cost of acquisition devices). Although the first algorithms were developed more than 50 years ago, sensing, feature extraction and matching techniques are being continuously improved, making it possible nowadays to automatically process also low quality impressions in a very short time.

In the year 2000, the Biometric System Laboratory of the University of Bologna, together with the Biometric Test Center of the San Jose State University and the Pattern Recognition and Image Processing Laboratory of the Michigan State University, organized the first Fingerprint Verification Competition (FVC2000). FVC2000 received great attention from both academic and commercial organizations; several research groups started using FVC2000 datasets for their experimentations and some companies, which initially did not participate in the competition, requested the organizers to certify their performance on the FVC2000 benchmark. The great encouragement received, induced the authors to organize similar initiatives in the year 2002 (FVC2002) and 2004 (FVC2004, which at the time this paper is being written, is still in progress).

Very recently (July 2003), NIST was mandated by the Justice Management Division of Dept. Of Justice, to organize the Fingerprint Vendor Technology Evaluation (FpVTE) [11], following the positive experience of its two analogous initiatives in the field of face recognition (FRVT2000 and FRVT2002 [12]). FpVTE results are expected for the first months of 2004.

FVC and FpVTE are technology evaluations [10] in the sense that their aim is comparing the basic technology (i.e., the algorithms) over given databases. Results are reproducible and different algorithms are directly comparable; on the other hand, only part of each biometric systems is evaluated, excluding hardware (e.g., the scanner) and the proprietary solutions to improve robustness and accuracy (e.g., quality control modules to reject poor quality fingerprints, visual feedback to help users in optimally positioning their fingers, multiple enrollments).

Evaluations of complete fingerprint-based biometric systems have been done in other initiatives (including some EU projects and national programs) [13] [14] [15]; a mention is also due to the IBG Comparative Biometric Testing (CBT), currently at the 5$^{th}$ round, where complete commercial biometric systems have been tested. Unfortunately such kind of scenario and operational evaluations are very expensive to organize, tests are not reproducible (each authentication require the presence of the user) and the results of most of them are statistically not relevant due to the small number of attempts.

This paper provides an overview of the three FVC competitions, briefly describing the databases and the protocols for algorithm submission and performance evaluation. Table 2 compares the three events from a general point of view, highlighting two main changes: the introduction of anonymous participation in FVC2002, and of the two categories (sub-competitions using the same databases) in FVC2004. Section 2 briefly describes the four databases used in each competition, while section 3 summarizes FVC submission rules. In section 4, the criteria and the procedures used for performance evaluation are presented, and the overall performance of the participant algorithms on FVC2000 and FVC2002 are reported. Finally, section 5 draws some conclusions.

## 2. Databases

Four new databases were created for each FVC competition: each database contains 880 fingerprints from 110 different fingers (8 impressions per finger), collected using the "three bears rule" (not too easy, not too hard) [10]. The first three databases were collected using commercially available scanners (see table 1), while the fourth one was generated with the SFinGE software [6] [7]. Each database was split into a sequestered "test" set of 800 images (set A) and an "training" set of 80 images (set B) made available to participants for parameters tuning before the submission of their algorithms; the benchmark used in each competition is constituted by sets A of the databases.

Table 1 summarizes the global features of the four databases for each competition, and figures 1 and 2 show

sample images from FVC2000 and FVC2002, respectively; images from FVC2004 cannot be disclosed yet.

Table 1. Scanners and technologies used for the databases of FVC competitions.

| | | Technology | Image | Resolution |
|---|---|---|---|---|
| FVC2000 | DB1 | Optical Sensor | 300×300 | 500 dpi |
| | DB2 | Capacitive Sensor | 256×364 | 500 dpi |
| | DB3 | Optical Sensor | 448×478 | 500 dpi |
| | DB4 | Synthetic Generator | 240×320 | About 500 dpi |
| FVC2002 | DB1 | Optical Sensor | 388×374 | 500 dpi |
| | DB2 | Optical Sensor | 296×560 | 569 dpi |
| | DB3 | Capacitive Sensor | 300×300 | 500 dpi |
| | DB4 | Synthetic Generator | 288×384 | About 500 dpi |
| FVC2004 | DB1 | Optical Sensor | 640×480 | 500 dpi |
| | DB2 | Optical Sensor | 328×364 | 500 dpi |
| | DB3 | Thermal Sweeping Sensor | 300×480 | 512 dpi |
| | DB4 | Synthetic Generator | 288×384 | About 500 dpi |

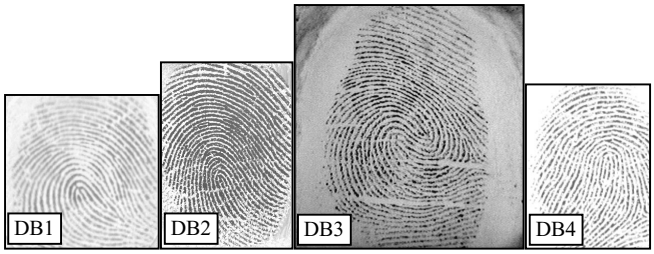


Figure 1. FVC2000: sample images taken from DB1, DB2, DB3 and DB4. In order to show the different image sizes of each database, the four images are displayed at the same scale factor.

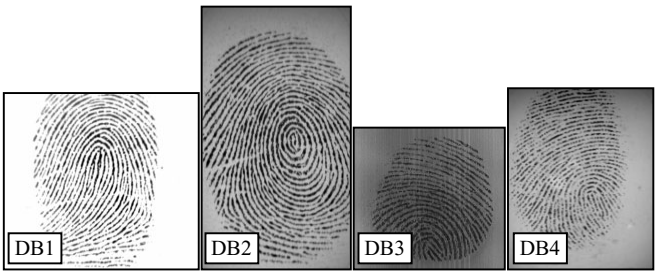


Figure 2. FVC2002: sample images taken from DB1, DB2, DB3 and DB4. In order to show the different image sizes of each database, the four images are displayed at the same scale factor.

## 3. Algorithm submission

The FVC protocol defining the format of the submitted algorithms was defined in FVC2000 and remained unchanged in FVC2002 and FVC2004.

Each participant is required to submit two executables in the form of "win32 console application". 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 responsibility of the participant's code; these files can also contain pre-computed data to save time during enrollment and matching.

Once all the executables have been submitted, feedback is sent to the participants by providing them the results of their algorithms over the training set B (the same data set they had previously been given) to allow them to verify that neither run-time problems nor hardware-dependent misbehaviors occurred.

## 4. Performance evaluation

This section summarizes how the FVC evaluation is executed and performance are measured, highlighting the additions and modifications introduced in new editions. For a throughout description, the reader should refer to [4] [5].

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

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

Then, for each database:

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

Table 5 shows the performance indicators measured and reported for each database and for each algorithm in FVC competitions. 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 concessions under false identity, the system "falsely accepts" an applicant if his/her fingerprint is "falsely rejected"; otherwise, a "false acceptance" causes a "false rejection". 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, which are the values of FNMR for FMR=1/100 and 1/1000, respectively, were reported since FVC2002. These data are useful to characterize the accuracy of fingerprint-based systems, which are often operated far from the EER point, by using thresholds which reduce FMR at the cost of high FNMR. FVC2004 introduced indicators measuring the amount of memory allocated by the algorithms and the template size.

Table 2. The three FVC competitions: a comprehensive view.

| | **FVC2000** | **FVC2002** | **FVC2004** |
|---|---|---|---|
| Call for participation | November, 1999 | October, 2001 | April, 2003 |
| Registration deadline | March 1st, 2000 | January 10th, 2002 | October 15th, 2003 |
| Submission deadline | June 1st, 2000 | March 1st, 2002 | November 30th, 2003 |
| Evaluation period | July–August, 2000 | April–July, 2002 | January–February 2004 |
| Notes | Anonymous part. not allowed | Anonymous part. allowed | Anonymous part. allowed<br>Two categories: *Open* and *Light* |
| Registered participants | 25 (15 withdrew) | 48 (19 withdrew) | 110 (64 withdrew) |
| Algorithms evaluated | 11 | 31 | *Open Cat.*: 41<br>*Light Cat.*: 26 |
| Presentation of the results | 15th ICPR<br>Barcelona, September 2000 | 16th ICPR<br>Quebec City, August 2002 | Results not yet presented |
| Databases | 4 (set A: 100x8, set B: 10x8) | 4 (set A: 100x8, set B: 10x8) | 4 (set A: 100x8, set B: 10x8) |
| DB1 | Optical (KeyTronic) | Optical (Identix) | Optical (CrossMatch) |
| DB2 | Capacitive (ST Microelectronics) | Optical (Biometrika) | Optical (Digital Persona) |
| DB3 | Optical (Identicator Technology) | Capacitive (Precise Biometrics) | Thermal-sweeping (Atmel) |
| DB4 | Synthetic (SFinGe v2.0) | Synthetic (SFinGe v2.51) | Synthetic (SFinGe v3.0) |
| DB availability | DVD accompanying the "Handbook of Fingerprint Recognition" [8] | | Not yet available |
| Website | http://bias.csr.unibo.it/fvc2000<br>(more than 38,000 accesses) | http://bias.csr.unibo.it/fvc2002<br>(more than 37,000 accesses) | http://bias.csr.unibo.it/fvc2004<br>(more than 10,000 accesses) |
| HW/SW used for running the evaluation | Pentium III (450 MHz)<br>Windows NT<br>FVC Test suite v1.0 | Pentium III (933 MHz)<br>Windows 2000<br>FVC Test suite v1.2 | Athlon 1600+ (1,41 GHz)<br>Windows XP<br>FVC Test suite v2.0 |
| Enrollment time limit | 15 seconds | 10 seconds | *Open Cat.*: 10 seconds<br>*Light Cat.*: 0.5 seconds |
| Match time limit | 5 seconds | 5 seconds | *Open Cat.*: 5 seconds<br>*Light Cat.*: 0.3 seconds |
| Memory size limit | Not enforced | Not enforced | *Open Cat.*: Not enforced<br>*Light Cat.*: 4 MBytes |
| Template size limit | Not enforced | Not enforced | *Open Cat.*: Not enforced<br>*Light Cat.*: 2 KBytes |

Table 3. FVC2000 average results over the four databases, sorted by average EER (only the first five entries are reported).

| ID | Organization | Type | Avg EER (%) | Avg FTE (%) | Avg Enroll Time (sec) | Avg Match Time (sec) |
|---|---|---|---|---|---|---|
| SAG1 | SAGEM SA (France) | Company | 1.73 | 0.00 | 3.18 | 1.22 |
| SAG2 | SAGEM SA (France) | Company | 2.28 | 0.00 | 1.11 | 1.11 |
| CSPN | Centre for Signal Processing, Nanyang Tech. Univ. (Singapore) | Academic | 5.19 | 0.14 | 0.20 | 0.20 |
| CETP | CEFET-PR / Antheus Technologia Ltda (Brasil) | Academic | 6.32 | 0.00 | 0.95 | 1.06 |
| CWAI | Centre for Wavelets, National University of Singapore (Singapore) | Academic | 7.08 | 4.46 | 0.27 | 0.35 |

Table 4. FVC2002 average results over the four databases, sorted by average EER (only the first five entries are reported).

| ID | Organization | Type | Avg EER (%) | Avg FMR 100 (%) | Avg FMR 1000 (%) | Avg Zero FMR (%) | Avg Enroll Time (sec) | Avg Match Time (sec) |
|---|---|---|---|---|---|---|---|---|
| PA15 | Bioscrypt Inc (United States) | Industry | 0.19 | 0.15 | 0.28 | 0.38 | 0.11 | 1.97 |
| PA27 | <anonymous> | Industry | 0.33 | 0.28 | 0.56 | 1.44 | 2.12 | 1.98 |
| PB27 | <anonymous> | Industry | 0.41 | 0.34 | 0.59 | 1.29 | 1.23 | 1.13 |
| PB15 | Bioscrypt Inc. (United States) | Industry | 0.77 | 0.77 | 1.04 | 1.29 | 0.07 | 0.22 |
| PB05 | Siemens AG (Germany) | Industry | 0.92 | 1.46 | 1.87 | 2.29 | 0.48 | 0.52 |

In FVC2000, FTE (Failure To Enroll) errors were recorded separately from the FMR/FNMR errors. Algorithms rejecting poor quality fingerprints at enrollment time could be implicitly favored since many problematic comparisons could be avoided. This could make it difficult to directly compare the accuracy of different algorithms. To avoid this problem, since FVC2002, FTE errors have been included into the computation of FMR and FNMR.

Table 5. FVC performance indicators.

| Performance indicator | 2000 | 2002 | 2004 |
|---|---|---|---|
| Genuine and impostor score histograms | √ | √ | √ |
| FMR and FNMR graph | √ | √ | √ |
| ROC graph | √ | √ | √ |
| Failure To Enroll Rate | √ | √ | √ |
| Failure To Match Rate | √ | √ | √ |
| Equal Error Rate (EER) | √ | √ | √ |
| FMR100 | | √ | √ |
| FMR1000 | | √ | √ |
| ZeroFMR | √ | √ | √ |
| ZeroFNMR | √ | √ | √ |
| Average match time | √ | √ | √ |
| Average enroll time | √ | √ | √ |
| Maximum memory allocated for enrollment | | | √ |
| Maximum memory allocated for match | | | √ |
| Average template size | | | √ |
| Maximum template size | | | √ |

Tables 3 and 4 report the average results over the four databases, for FVC2000 and FVC2002, respectively; for detailed results, the reader should refer to [4] [5] and to the competition websites [1] [2] [3]. FVC2004 results are not available at the time this paper is being written.

## 5. Conclusions

In the last decade, some technology evaluations of fingerprint-based biometric systems have been carried out. These technology evaluations are not official performance certifications of biometric systems, since:

- the databases used have not been acquired in a real environment and according to a formal protocol;
- only part of the software is evaluated, by using images from sensors not native to each system.

Nevertheless, they:

- give a useful overview of the state-of-the-art in fingerprint recognition;
- allow researchers and companies to test their algorithms over common databases collected using different technologies;
- provide guidance to the participants for improving their algorithms.

Initiatives similar to FVC and FpVTE are increasingly being organized for other biometrics (face, voice, hand and signature); we firmly believe that this will accelerate the development of working biometric solutions giving to the potential users an unbiased view of this technology.

## References


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