Evaluating Morphing Attack Detectors

An Overview of the Bologna Online Evaluation Platform (BOEP)

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About: Biometric System Lababoratory (BioLab)

The Biometric System Laboratory is active at the University of Bologna since 1993.

The main research efforts are devoted to fingerprint and face recognition and to performance evaluation of biometric systems. Collaborations with industrial partners ensure that the research activities are linked to real applications.

People:

Professors: Davide Maltoni, Matteo Ferrara, Annalisa Franco, Raffaele Cappelli, Alessandra Lumini

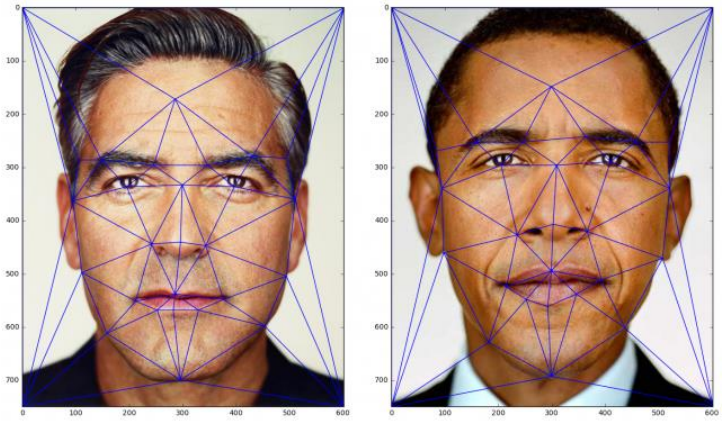
Researchers: Guido Borghi, Lorenzo Pellegrini

PhD Students: Matteo Scucchia, Lorenzo Vorrabbi

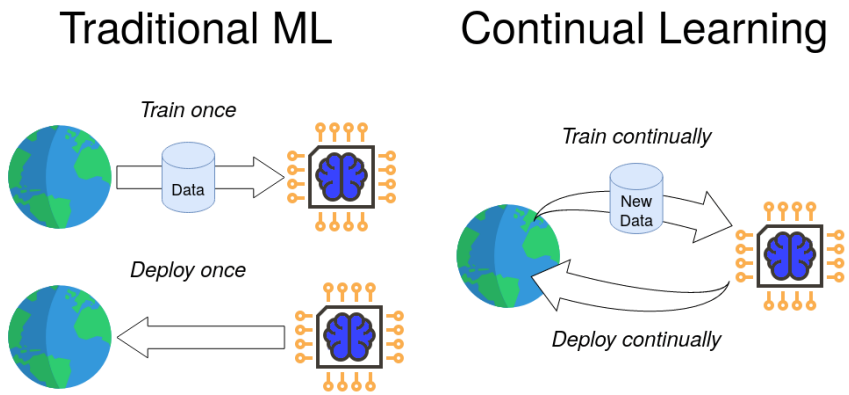
Fellows: Nicolò Di Domenico

BioLab + MI @ BioLab: main topics

Biometrics



Face Morphing



Continual Learning

BioLab (biometric systems only):
https://biolab.csr.unibo.it/

Machine Intelligence @ BioLab:
https://miatbiolab.csr.unibo.it/

Goal

The goal is to provide a trusted platform that can be used to evaluate the performance of algorithms in various biometric fields.

BOEP is based on the FVC-ongoing platform:

- It started as FVC, the international **F**ingerprint **V**erification **C**ompetitions organized in 2000, 2002, 2004, and 2006
- From 2009 is an onGoing competition platform used by both academy institutions and industry
- Now also covers face recognition tasks, including Morphing Attack Detection

How it works

- Academic groups, industry actors, and independent developers can register on the web site
- Participants can upload their algorithms in various formats
- Tests are carried out on sequestered datasets in a controlled environment
    - No internet connection
    - Input order randomization
    - Standardized software setup
- Common performance indicators and metrics are reported
- The participants can decide to publish the results on a public leaderboard

For a complete list of available benchmarks (FVC-ongoing):

https://biolab.csr.unibo.it/fvcongoing/UI/Form/Benchmarks.aspx

Bologna Online Evaluation Platform benchmarks:

https://biolab.csr.unibo.it/fvcongoing/UI/Form/BOEP.aspx

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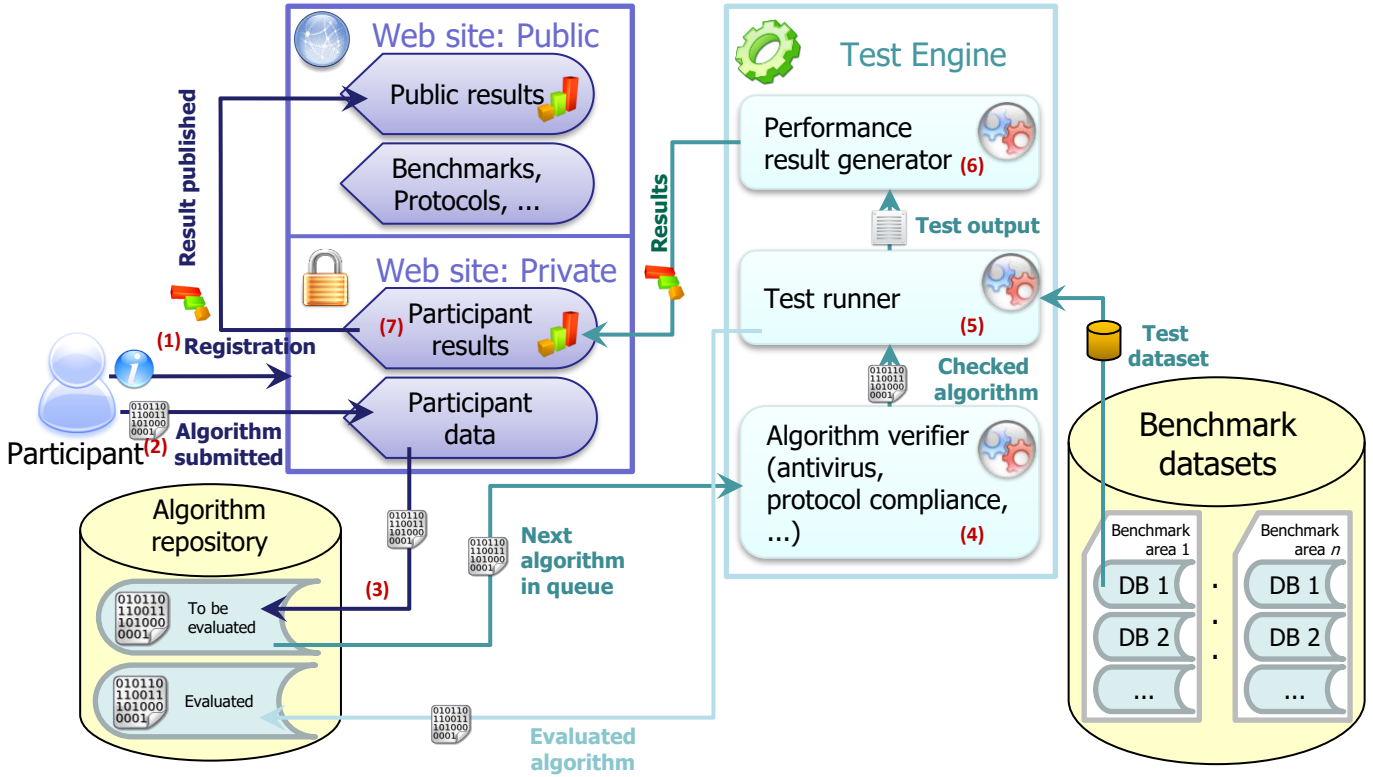
Main steps



A given participant, after registering to the Web Site (1), submits some algorithms (2) to one or more of the available benchmarks; the algorithms are stored in a specific repository (3). Each algorithm is evaluated by the Test Engine that (4), executes it on the selected benchmark (5) and processes its outputs to generate (6) all the results (e.g. EER, score graphs), which are published (7) on the Web Site.

FVC-onGoing: stats (January 2024)

Registered Participants by Organization Type	
Academic Research Group	333
Company	301
Independent Developer	1254

Published Results by Benchmark Area	
Differential Morph Attack Detection	**30**
Single-image Morph Attack Detection	**19**
Fingerprint Matching (ISO)	103
Secure Template Fingerprint Verification	8
Fingerprint Verification	86
Fingerprint Orientation Extraction	14
Palmprint Verification	45
Face Image ISO Compliance Verification	10
Fingerprint Indexing	12

Algorithms Evaluated by Benchmark Area	
Differential Morph Attack Detection	**282**
Single-image Morph Attack Detection	**174**
Fingerprint Matching (ISO)	2837
Secure Template Fingerprint Verification	60
Fingerprint Verification	2384
Fingerprint Orientation Extraction	616
Palmprint Verification	635
Face Image ISO Compliance Verification	1242
Fingerprint Indexing	231

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Benchmark Areas – FVC-onGoing 1/2

Benchmark area	Benchmarks
Fingerprint Verification	FV-STD-1.0 FV-TEST FV-HARD-1.0
Palmprint Verification	PV-TEST-FULL PV-TEST-PARTIAL PV-FULL-1.0 PV-PARTIAL-1.0
Fingerprint Matching (ISO)	FMISO-STD-1.0 FMISO-TEST FMISO-HARD-1.0
Fingerprint Indexing	FIDX-TEST FIDX-10K-1.0 FIDX-50K-1.0

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Benchmark Areas – FVC-onGoing 2/2

Benchmark area	Benchmarks
Fingerprint Orientation Extraction	FOE-TEST FOE-STD-1.0
Secure Template Fingerprint Verification	STFV-TEST STFV-STD-1.0 STFV-HARD-1.0
Face Image ISO Compliance Verification	FICV-TEST FICV-1.0

Benchmark Areas: BOEP

- Two benchmark areas: single-image and differential

Single-image Morph Attack Detection

This benchmark area contains face morphing detection benchmarks. Morphing detection consists in analyzing an ISO compliant face image to determine whether it is the result of a morphing process (mixing faces of two subjects) or not. Algorithms submitted to these benchmarks are required to analyze an image and produce a score representing the probability of the image to be morphed. Read more...

Differential Morph Attack Detection

This benchmark area contains face morphing detection benchmarks. Morphing detection consists in analyzing an ISO compliant face image to determine whether it is the result of a morphing process (mixing faces of two subjects) or not. Algorithms submitted to these benchmarks are required to compare a bona fide (not morphed) image to a suspected image and produce a score representing the probability of the suspected image to be morphed. Read more...

S-MAD Benchmarks

Benchmarks	Format	Bona Fide Attempts	Morphing Attempts
SMAD-SOTAMD_D-1.0	Digital	300	2045
SMAD-SOTAMD_P&S-1.0	Printed & Scanned	1096	3703
SMAD-SOTAMD_PM_D-1.0	Digital	300	470
SMAD-SOTAMD_UC_P&S-1.0	Printed & Scanned	200	380
SMAD-IMARS-HQ_FULL-1.0	Digital	300	25200
SMAD-IMARS-HQ_SMALL-1.0	Digital	300	5040
SMAD-IMARS-HQ_HARD-1.0	Digital	300	6522
SMAD-IMARS-MQ_FULL-1.0	Digital	205	7652
SMAD-IMARS-MQ_SMALL-1.0	Digital	205	1530
SMAD-IMARS-MQ_HARD-1.0	Digital	205	1142

https://biolab.csr.unibo.it/fvcongoing/UI/Form/BenchmarkAreas/BenchmarkAreaSMAD.aspx

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D-MAD Benchmarks

Benchmarks	Format	Bona Fide Attempts	Morphing Attempts
DMAD-SOTAMD_D-1.0	Digital	3000	30550
DMAD-SOTAMD_P&S-1.0	Printed & Scanned	10960	55530
DMAD-SOTAMD_PM_D-1.0	Digital	3000	7050
DMAD-SOTAMD_UC_P&S-1.0	Printed & Scanned	2000	5700
DMAD-IMARS-HQ_FULL-1.0	Digital	3000	504000
DMAD-IMARS-HQ_SMALL-1.0	Digital	3000	50400
DMAD-IMARS-HQ_HARD-1.0	Digital	3000	130440
DMAD-IMARS-MQ_FULL-1.0	Digital	2187	158986
DMAD-IMARS-MQ_SMALL-1.0	Digital	2187	15899
DMAD-IMARS-MQ_HARD-1.0	Digital	2187	34698

https://biolab.csr.unibo.it/fvcongoing/UI/Form/BenchmarkAreas/BenchmarkAreaDMAD.aspx

BOEP Areas: additional info

- Each benchmarks has different complexity elements:
  - Some benchmark images are obtained after a Print & Scan procedure, while others present purely Digital photos
  - Some benchmarks consist of manually retouched images
  - For IMARS, 4 HARD benchmarks (2 for SMAD and 2 for DMAD) containing images able to fool three commercial face recognition systems is available
  - Different ranges of morphing factors
- A "test" benchmark is always available to check if the submission works correctly

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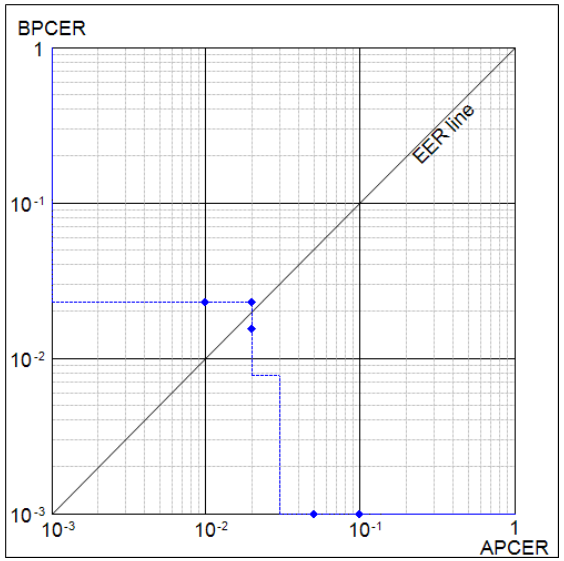
Results: example

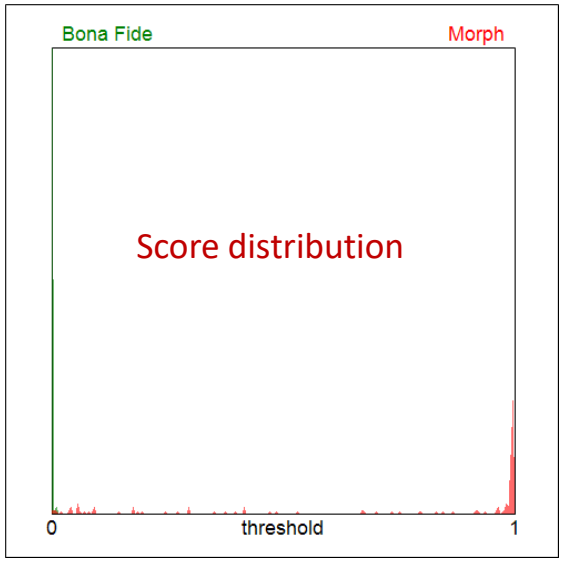
Main performance indicators

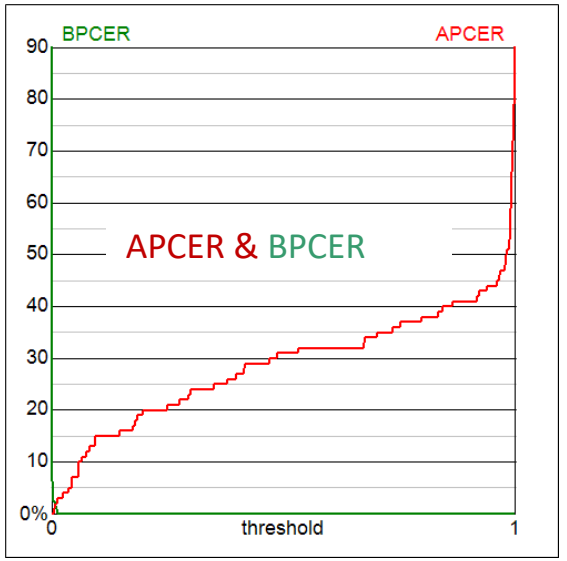
Accuracy indicators				
Accuracy	**EER**	**$BPCER_{10}$**	**$BPCER_{20}$**	**$BPCER_{100}$**
86,52%	1,77% (1,54% - 2,00%)	0%	0%	2,31%

Detection failures	
REJ_{NBFRA}	**REJ_{NMRA}**
0%	0%

Detailed Graphs







Current published results: Single-image Morph Attack Detection

Published on	Benchmark	Participant	Type	Algorithm	Version	EER	$BPCER_{10}$	$BPCER_{20}$	$BPCER_{100}$
16/01/2023	SMAD-SOTAMD_P&S-1.0	Biometric System Laboratory	Academic Research Group	Inception-Resnet P&S	1.0	24.63 %	51.28 %	68.25 %	91.42 %
16/01/2023	SMAD-SOTAMD_D-1.0	Biometric System Laboratory	Academic Research Group	Inception-Resnet	3.0	10.33 %	11.67 %	23.67 %	48.00 %
22/12/2022	SMAD-BIOLAB-1.0	Biometric System Laboratory	Academic Research Group	Inception-Resnet	2.0	9.55 %	9.09 %	11.36 %	64.77 %
05/12/2022	SMAD-MORPHDB_D-1.0	Biometric System Laboratory	Academic Research Group	Inception-Resnet	1.0	1.77 %	0.00 %	0.00 %	3.08 %
19/07/2022	SMAD-MORPHDB_D-1.0	Norwegian University of Science and Technology	Academic Research Group	Multimodal S-MAD	1	23.92 %	40.77 %	49.23 %	78.46 %
19/07/2022	SMAD-BIOLAB-1.0	Norwegian University of Science and Technology	Academic Research Group	Multimodal S-MAD	1	40.45 %	78.41 %	85.23 %	100.00 %
16/10/2020	SMAD-SOTAMD_P&S-1.0	Norwegian University of Science and Technology	Academic Research Group	NTNU	1.0	54.37 %	94.89 %	98.27 %	99.91 %
16/10/2020	SMAD-SOTAMD_D-1.0	Norwegian University of Science and Technology	Academic Research Group	NTNU	1.0	31.80 %	65.00 %	79.33 %	91.67 %
15/10/2020	SMAD-SOTAMD_D-1.0	Hochschule Darmstadt	Academic Research Group	PRNU	4.0.0	44.81 %	100.00 %	100.00 %	100.00 %
15/10/2020	SMAD-SOTAMD_P&S-1.0	Hochschule Darmstadt	Academic Research Group	PRNU	4.0.0	48.04 %	85.86 %	97.35 %	100.00 %
15/10/2020	SMAD-SOTAMD_D-1.0	Hochschule Darmstadt	Academic Research Group	Laplace	2.0.0	42.32 %	78.00 %	82.67 %	93.33 %
15/10/2020	SMAD-SOTAMD_P&S-1.0	Hochschule Darmstadt	Academic Research Group	Laplace	2.0.0	45.52 %	85.86 %	96.90 %	100.00 %
09/10/2020	SMAD-SOTAMD_P&S-1.0	University of Twente	Academic Research Group	MBLBP	1.2	43.34 %	100.00 %	100.00 %	100.00 %
09/10/2020	SMAD-SOTAMD_D-1.0	University of Twente	Academic Research Group	MBLBP	1.2	41.38 %	100.00 %	100.00 %	100.00 %
29/09/2020	SMAD-SOTAMD_P&S-1.0	Biometric System Laboratory	Academic Research Group	Deep-S-MAD	1.0	37.10 %	100.00 %	100.00 %	100.00 %
29/09/2020	SMAD-SOTAMD_D-1.0	Biometric System Laboratory	Academic Research Group	Deep-S-MAD	1.0	38.99 %	100.00 %	100.00 %	100.00 %

Current published results: Differential Morph Attack Detection

Published on ▼	Benchmark	Participant	Type	Algorithm	Version	EER	$BPCER_{10}$	$BPCER_{20}$	$BPCER_{100}$
15/01/2024	DMAD-SOTAMD_D-1.0	Vision-Box	Company	VBDMAD	1.0.0	2.60 %	0.40 %	0.70 %	8.50 %
15/01/2024	DMAD-MORPHDB_D-1.0	Vision-Box	Company	VBDMAD	1.0.0	0.19 %	0.00 %	0.00 %	0.00 %
22/11/2023	DMAD-SOTAMD_D-1.0	University of Twente	Academic Research Group	dlib_dmad_enroll	1.0	15.77 %	24.13 %	38.57 %	100.00 %
27/10/2023	DMAD-SOTAMD_D-1.0	Biometric System Laboratory	Academic Research Group	ACIdA	1.1	7.84 %	7.57 %	12.60 %	26.23 %
18/10/2023	DMAD-SOTAMD_D-1.0	Biometric System Laboratory	Academic Research Group	Siamese	1.0	23.37 %	35.03 %	48.97 %	93.60 %
18/10/2023	DMAD-SOTAMD_D-1.0	Biometric System Laboratory	Academic Research Group	R-DMAD	2.0	10.23 %	10.33 %	19.67 %	47.47 %
30/01/2023	DMAD-SOTAMD_P&S-1.0	Hochschule Darmstadt	Academic Research Group	MagFace	1	4.83 %	0.84 %	4.39 %	100.00 %
22/10/2020	DMAD-SOTAMD_D-1.0	Hochschule Darmstadt	Academic Research Group	DFR	2.0.0	4.54 %	2.00 %	3.93 %	18.87 %
22/10/2020	DMAD-SOTAMD_P&S-1.0	Hochschule Darmstadt	Academic Research Group	DFR	2.0.0	4.62 %	1.77 %	4.08 %	19.70 %
16/10/2020	DMAD-SOTAMD_D-1.0	Norwegian University of Science and Technology	Academic Research Group	DN	1.0	52.03 %	89.70 %	94.70 %	98.57 %
16/10/2020	DMAD-SOTAMD_P&S-1.0	Norwegian University of Science and Technology	Academic Research Group	DN	1.0	50.13 %	90.26 %	95.37 %	99.18 %
15/10/2020	DMAD-SOTAMD_P&S-1.0	Hochschule Darmstadt	Academic Research Group	WL	2.0.0	36.17 %	70.37 %	82.75 %	95.58 %
15/10/2020	DMAD-SOTAMD_D-1.0	Hochschule Darmstadt	Academic Research Group	WL	2.0.0	37.13 %	71.67 %	83.27 %	95.67 %
15/10/2020	DMAD-SOTAMD_P&S-1.0	Hochschule Darmstadt	Academic Research Group	Laplace	2.0.0	58.41 %	95.49 %	97.85 %	99.44 %
15/10/2020	DMAD-SOTAMD_D-1.0	Hochschule Darmstadt	Academic Research Group	Laplace	2.0.0	55.13 %	96.70 %	98.67 %	99.87 %
15/10/2020	DMAD-SOTAMD_D-1.0	Hochschule Darmstadt	Academic Research Group	MBLBP	6.0.0	33.47 %	52.80 %	59.93 %	74.80 %

Performance indicators: dataset splits

Subset	Bona Fide	Morphing	EER	$BPCER_{10}$	$BPCER_{20}$	$BPCER_{100}$
Morphing Factor=0.3	3000	10350	22.66% (22.66% - 22.67%)	29.47%	37.00%	77.10%
Morphing Factor=0.5	3000	20200	25.00%	38.37%	54.70%	94.00%
Female	1280	13090	23.83%	41.09%	67.58%	95.55%
Male	1720	17460	23.25% (23.25% - 23.26%)	31.74%	41.74%	79.53%
African Ethnicity	520	6060	26.15% (26.14% - 26.15%)	39.81%	68.85%	100.00%
East Asian Ethnicity	180	1990	24.00% (23.89% - 24.12%)	30.00%	40.56%	100.00%
European/American Ethnicity	1920	21510	22.60%	34.74%	48.96%	88.85%
Indian/Asian Ethnicity	200	2760	13.99% (13.99% - 14.00%)	14.00%	38.50%	66.00%
Middle Eastern Ethnicity	180	2660	22.76% (22.74% - 22.78%)	26.11%	28.33%	75.56%
Age: 18-35	1740	21200	18.67% (18.67% - 18.68%)	25.00%	34.54%	71.09%
Age: 36-55	940	13670	27.02%	46.60%	63.83%	96.91%
Age: 56-75	320	4130	37.18% (37.17% - 37.19%)	52.81%	75.63%	94.38%
Trait: Freckels	200	5290	26.49% (26.48% - 26.50%)	31.00%	41.50%	100.00%
Trait: Moles	340	7330	21.47% (21.46% - 21.47%)	32.94%	71.76%	99.71%
No Specific Trait	2190	26600	21.66% (21.64% - 21.67%)	31.69%	43.65%	80.32%
Hochshule Darmstadt Images	1000	11850	25.80%	37.70%	54.40%	73.20%
Norwegian University of Science and Technology Images	1000	9100	9.50% (9.49% - 9.50%)	9.40%	18.50%	44.40%
University of Twente Images	1000	9600	27.80% (27.79% - 27.80%)	43.60%	100.00%	100.00%
Automatic Post-processing	3000	23500	23.43%	35.10%	48.17%	93.60%
Manual Post-processing	3000	7050	23.32% (23.30% - 23.33%)	34.93%	50.33%	91.20%
Morphing Algorithm: C01	3000	4750	23.23% (23.22% - 23.23%)	34.53%	46.03%	83.37%
Morphing Algorithm: C02	3000	3000	22.67%	34.80%	52.47%	88.47%
Morphing Algorithm: C03	3000	6000	22.57%	30.13%	44.27%	93.93%
Morphing Algorithm: C05	3000	6300	24.01% (24.00% - 24.02%)	35.73%	49.13%	89.43%
Morphing Algorithm: C06	3000	6000	26.12% (26.10% - 26.13%)	37.97%	54.13%	93.97%
Morphing Algorithm: C07	3000	4500	23.68% (23.67% - 23.69%)	36.40%	51.97%	93.73%
Manual Post-process: PM01	3000	750	21.75% (21.73% - 21.77%)	29.57%	42.63%	75.57%

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Additional notes

- There are restrictions on the number of submissions a user can upload in a certain time span
- The submissions can take some time to be executed
    - This is especially true when using legacy formats
- Participants of published results may obtain good results in various ways
    - Training on private datasets
    - Use of proprietary algorithms (especially from industry participants)

BOEP – Algorithm Submission

To reduce participants efforts to prepare the submission package, it is possible to submit algorithms in one of the following three different forms:

- an executable in the form of a Win32 console application;
- a Python script;
- a Linux dynamically-linked library compliant to NIST FRVT MORPH specifications.

A detailed description of the submission requirements is reported on the web site.

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Navigating the website and submitting an algorithm

Hands-on…

BOEP vs NIST

Execution environment:

- BOEP: environment can be reproduced locally using Docker…
    - … and can be updated quickly on request (adding and updating libraries, …)
- NIST: based on .ISO images (Ubuntu only)
    - Algorithms are executed on the latest version of the ".ISO" only

Submission format:

- BOEP: Python script (with GPU support), NIST format, Win32 executable
- NIST: NIST format (Linux dinamycally linked library, C/C++ only)

BOEP Python format

```python
def initialize(
    alg_extra_data_folder_path: str
) -> ReturnCode:
    # Init Library and global resources ...
    return_code = ReturnCode.Success

    # ...

    return return_code

def detect_morph_differentially(
    suspected_morph_file_path: str,
    label: ImageLabel,
    probe_face_file_path: str
) -> Tuple[ReturnCode, bool, float]:
    # Algorithm implementation ...
    return_code = ReturnCode.Success
    is_morph = False
    score = 0.0

    # ...

    return return_code, is_morph, score
```

The BOEP Python script format is similar to the NIST C/C++ specification (same parameters, same return codes and values).

- Makes it easy to port existing algorithm to the new Python format
- `initialize`: load Deep Learning models, keypoint extractors, ...
- `detect_morph_differentially`: implements the DMAD algorithm
    - Similar interface for SMAD

Template available in the Downloads section of the platform.

Interface comparison

```python
def initialize(
    alg_extra_data_folder_path: str
) -> ReturnCode:
    # Init Library and global resources ...
    return_code = ReturnCode.Success

    # ...

    return return_code

def detect_morph_differentially(
    suspected_morph_file_path: str,
    label: ImageLabel,
    probe_face_file_path: str
) -> Tuple[ReturnCode, bool, float]:
    # Algorithm implementation ...
    return_code = ReturnCode.Success
    is_morph = False
    score = 0.0

    # ...

    return return_code, is_morph, score
```

Table 7 – Two-image Differential Morph Detection

Prototypes	ReturnStatus detectMorphDifferentially(	
	const Image &suspectedMorph,	Input
	const ImageLabel &label,	Input
	const Image &probeFace,	Input
	bool &isMorph,	Output
	double &score);	Output
Description	This function takes two input images - a known unaltered/not morphed image of the subject (`probeFace`) and an image of the same subject that's in question (may or may not be a morph) (`suspectedMorph`) with an associated image label describing the image format/origin. This function outputs a binary decision on whether `suspectedMorph` is a morph (given `probeFace` as a prior) and a "morphiness" score on [0, 1] indicating how confident the algorithm thinks the `suspectedMorph` is a morph, with 0 meaning confidence that the `suspectedMorph` is not a morph and 1 representing absolute confidence that it is a morph.	
Input Parameters	suspectedMorph	Input Image
	label	ImageLabel (Section 4.1.1) describing the format of the suspected morph image • NonScanned = non-scanned digital photo • Scanned = a photo that is printed, then scanned • Unknown = unknown photo format/origin
	probeFace	An image of the subject known not to be a morph (e.g., live capture image)
Output Parameters	isMorph	True if image contains a morph; False otherwise
	score	A score on [0, 1] representing how confident the algorithm is that the image contains a morph. 0 means certainty that image does not contain a morph and 1 represents certainty that image contains a morph.
Return Value	See General Evaluation Specifications document for all valid return code values. If this function is not implemented, the return code should be set to `ReturnCode::NotImplemented`. If this function is not implemented for a certain type of image, for example, the function supports non-scanned photos but not scanned photos, then the function should return `ReturnCode::NotImplemented` when the function is called with the particular unsupported image type.	

Interface comparison

```python
def initialize(
    alg_extra_data_folder_path: str
) -> ReturnCode:
    # Init Library and global resources ...
    return_code = ReturnCode.Success

    # ...

    return return_code

def detect_morph_differentially(
    suspected_morph_file_path: str,
    label: ImageLabel,
    probe_face_file_path: str
) -> Tuple[ReturnCode, bool, float]:
    # Algorithm implementation ...
    return_code = ReturnCode.Success
    is_morph = False
    score = 0.0

    # ...

    return return_code, is_morph, score
```

```cpp
#include <cstring>
#include <iostream>
#include "nullimplfrvtmorph.h"

using namespace std;
using namespace FRVT;
using namespace FRVT_MORPH;

NullImplFRVTMorph::NullImplFRVTMorph() {}

NullImplFRVTMorph::~NullImplFRVTMorph() {}

ReturnStatus
NullImplFRVTMorph::initialize(
    const std::string &configDir,
   const std::string &configValue) {
    // ...
    return ReturnStatus(ReturnCode::Success);
}

ReturnStatus
NullImplFRVTMorph::detectMorphDifferentially(
    const FRVT::Image &suspectedMorph,
    const FRVT_MORPH::ImageLabel &label,
    const FRVT::Image &liveFace,
    bool &isMorph,
    double &score) {
    // ...
    return ReturnStatus(ReturnCode::Success);
}
```