Face Morphing Attack Detections

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copy of slides available at:
https://christoph-busch.de/about-talks-slides.html
more information at:
https://christoph-busch.de/projects-mad.html
latest news at:
https://twitter.com/busch_christoph

CVPR 2021 Biometrics Workshop
June 19, 2021

ATHENE

European Association for Biometrics
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Human Identity in Europe

NORWEGIAN BIOMETRICS LABORATORY

NTNU

Overview

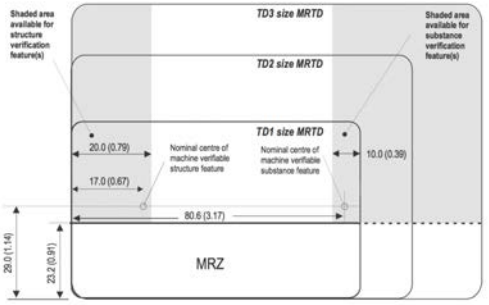
Agenda

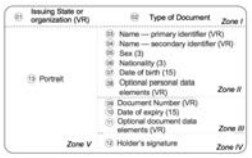
- Introduction - Problem description
- Morphing Attack Detection - Scenarios and Methods
- Status: Face Morphing Attack Detection
- Ongoing research activities

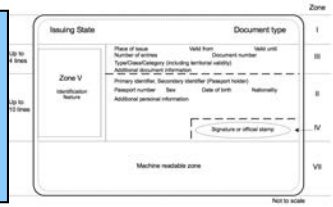
ICAO International Specifications

Doc 9303: relevant parts

Part 2: Specification for the Security of the Design	sizes of MRTD: TD1 (cards), TD2, TD3 (passports)
Part 3: Specifications Common to all MRTDs	physical characteristics, visual zone, MRZ, conventions, face image
Part 4: TD3 size MRTDs electronic Passports (MRP)	MRP data page (design and data fields), primary identifier, check digits
Part 5:TD1 size MRTDs electronic citizen cards	sequence of data elements, truncation rules
Part 7: Machine Readable Visas (MRV)	specification which allow both visual and machine readable means
Part 10: Logical Data Structure (LDS)	specification for both visual and mach. readable







Encoded Identification Feature(s)	Global Interchange Feature	DG2	Encoded Face
	Additional Feature(s)	DG3	Encoded Finger(s)
		DG4	Encoded Eye(s)

ICAO 9303 Logical Data Structure

Data stored on the chip (LDS)

- DG1: Information printed on the data page
- DG2: Facial image of the holder (mandatory)

- DG3: Fingerprint image of left and right index finger

- DG4: Iris image

....

- DG15: Active Authentication Public Key Info
- DG16: Persons to notify

Document Security Object

- Hash values of DGs

					DATA ELEMENTS
REQUIRED	ISSUING STATE OR ORGANIZATION DATA	Detail(s) Recorded in MRZ	DG1		Document Type
					Issuing State or organization
					Name (of Holder)
					Document Number
					Check Digit - Doc Number
					Nationality
					Date of Birth
					Check Digit - DOB
					Sex
					Data of Expiry or Valid Until Date
					Check Digit DOE/VUD
					Optional Data
					Check Digit - Optional Data Field
					Composite Check Digit
		Encoded Identification Feature(s)	Global Interchange Feature	DG2	Encoded Face
			Additional Feature(s)	DG3	Encoded Finger(s)
				DG4	Encoded Eye(s)
OPTIONAL	ISSUING STATE OR ORGANIZATION DATA	Displayed Identification Feature(s)	DG5		Displayed Portrait
			DG6		Reserved for Future Use
			DG7		Displayed Signature or Usual Mark
		Encoded Security Feature(s)	DG8		Data Feature(s)
			DG9		Structure Feature(s)
			DG10		Substance Feature(s)
			DG11		Additional Personal Detail(s)
			DG12		Additional Document Detail(s)
			DG13		Optional Detail(s)
			DG14		Security Options
			DG15		Active Authentication Public Key Info
			DG16		Person(s) to Notify

Source: ICAO 9303 Part 10, 2015

ICAO 9303 Logical Data Structure

Data to be stored in the RFID-Chip

- Alpha-numeric data: 5 Kbyte
- Facial image: ISO/IEC 19794-5:2005
  - 12 Kbyte (JPEG, JPEG2000)
- Fingerprint images: ISO/IEC 19794-4:2005
  - 2* 10 Kbyte (JPEG, JPEG2000, WSQ)

- Facial image: ISO/IEC 39794-5:2019
  https://www.iso.org/standard/72155.html
- Fingerprint images: ISO/IEC 39794-4:2019
  https://www.iso.org/standard/72156.html

Adopted by ICAO in in 2020

  - ICAO has adopted its 9303 specification in 2020 and refers now to ISO/IEC 39794 and its Parts 1, 4 and 5.
  - Passport reader equipment must be able to handle ISO/IEC 39794 data by 2025-01-01 (5 years preparation period).
  - Between 2025 and 2030, passport issuers can use the old version or the new version of standards (5 years transition period).

Principles

Principle of equality - in our society

- One individual - one passport

image source: https://pixabay.com/de/vectors/tick-sternchen-kreuz-rot-gr%C3%BCn-40678/

Is the Principle valid on the left Side?

Principle of equality - in our society

- One individual - one passport

Principle of unique link of ICAO

- One individual - one passport
- ICAO 9303 part 2, 2006:
  *„**Additional security measures:** inclusion of a machine verifiable biometric feature linking the document to its legitimate holder“*

image source: https://pixabay.com/de/vectors/tick-sternchen-kreuz-rot-gr%C3%BCn-40678/

Is the Principle valid on the left Side?

Principle of unique link of ICAO

- One individual - one passport

We don’t want this principle of unique link to be broken

- Multiple individuals - one passport

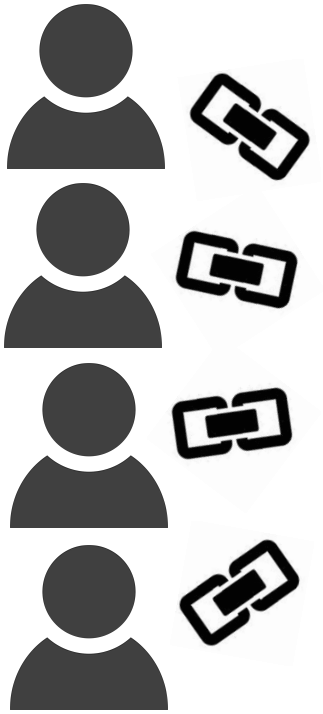


image source: https://pixabay.com/de/vectors/tick-sternchen-kreuz-rot-gr%C3%BCn-40678/

What is Morphing?

What is Morphing?

In our real world morphing can become a threat

- with a criminal and an accomplice as actors
- take the criminal
- and the accomplice
- morphing can transform one face image into the other

What is Morphing?

In our real world morphing can become a threat

- with a criminal and an accomplice as actors
- take the criminal
- and the accomplice
- morphing can transform one face image into the other
- and you can stop half way in the transformation

What is Morphing?

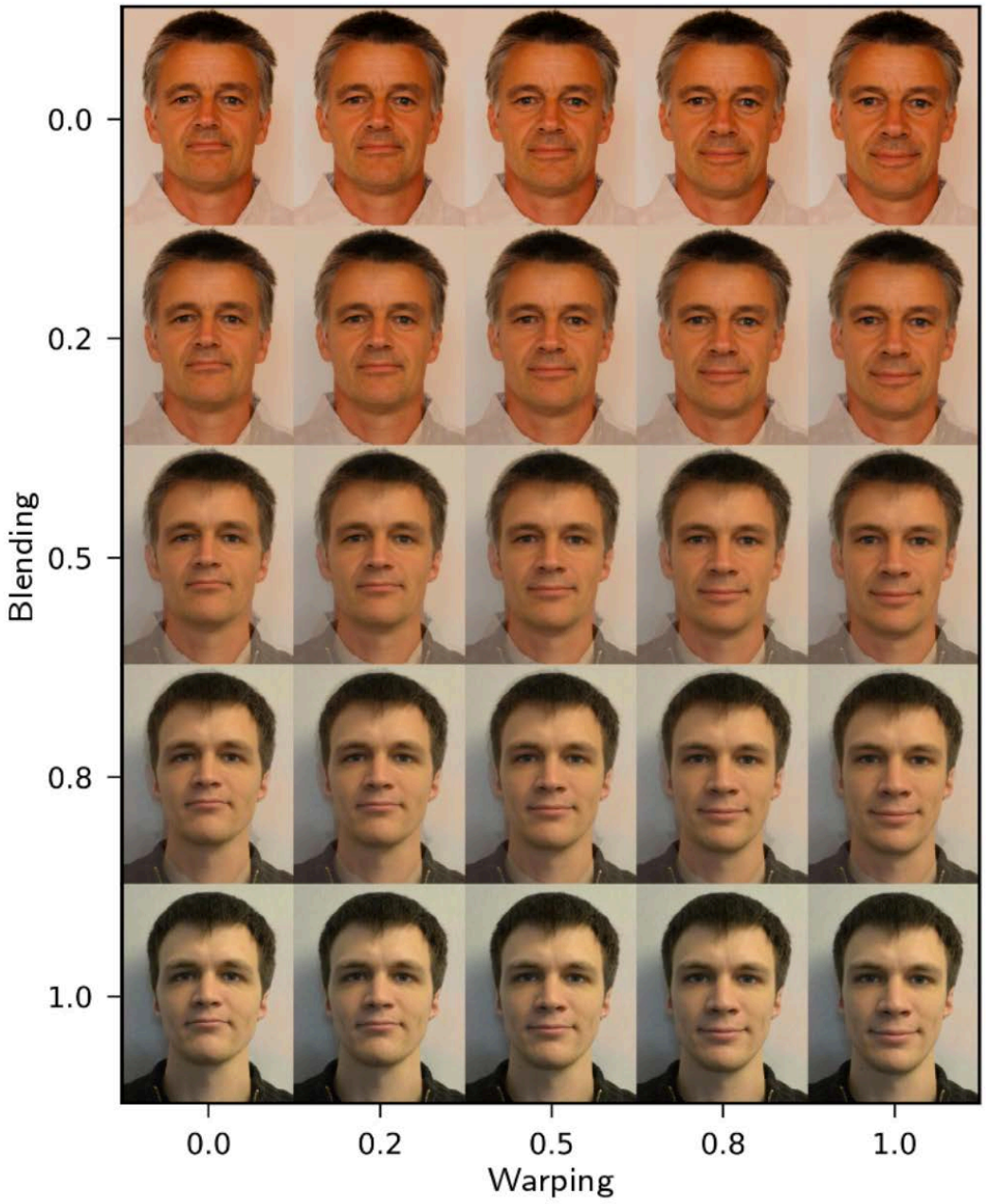
Warping and blending

- controlled by the alpha factor
- Landmark positions

$$\vec{x}_m = (1 - \alpha_w) \cdot \vec{x}_1 + \alpha_w \cdot \vec{x}_2$$

- Colour

$$C_m = (1 - \alpha_b) \cdot C_1 + \alpha_b \cdot C_2$$



A good Morph …

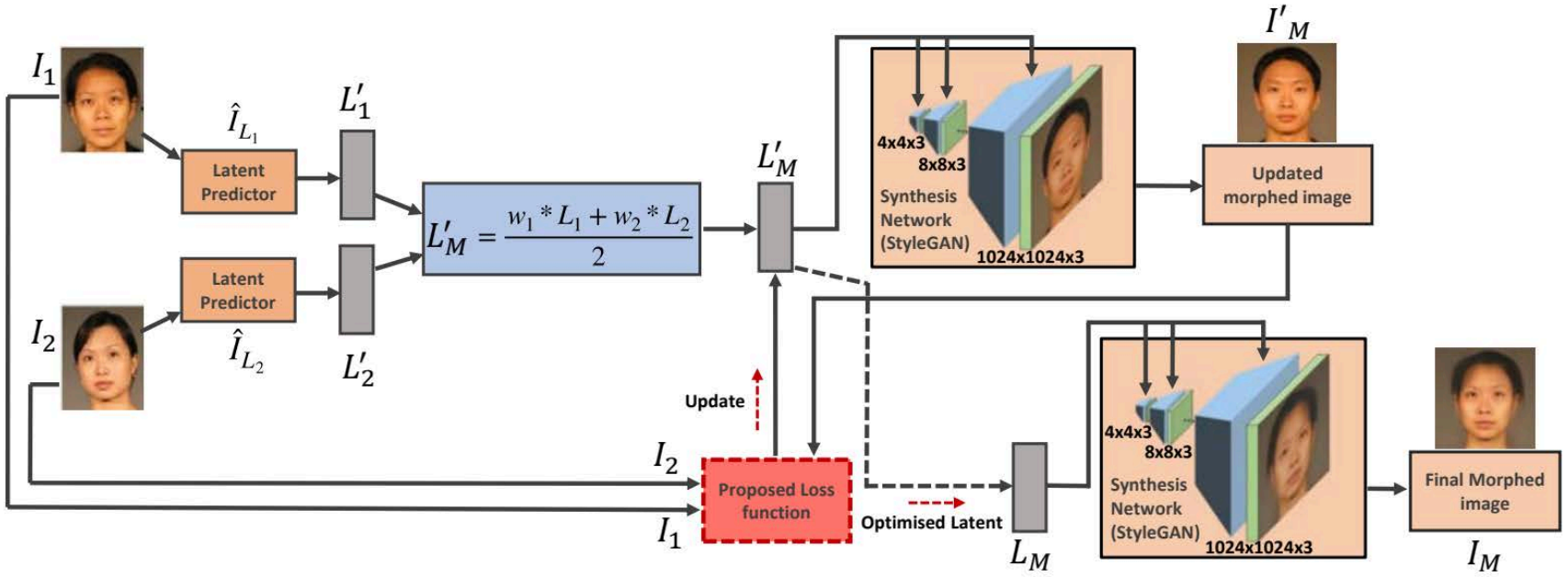
… is not as simple as you think

- Inaccurate landmarks, insufficient landmarks, fine details

A good Morph …

… generated with MIP-GAN

- Morphing through Identity Prior driven Generative Adversarial Network
  - high quality morphs
  - enforced identity priors



[Zhang2021] H. Zhang, S. Venkatesh, R. Raghavendra, K. Raja, N. Damer, C. Busch: "MIPGAN - Generating Strong and High Quality Morphing Attacks Using Identity Prior Driven GAN", in IEEE Transactions on Biometrics, Behavior, and Identity Science (TBIOM), (2021)

Problem Description

Problem: Morphing Attacks

Morphing attack scenario

- Passport application of the accomplice A

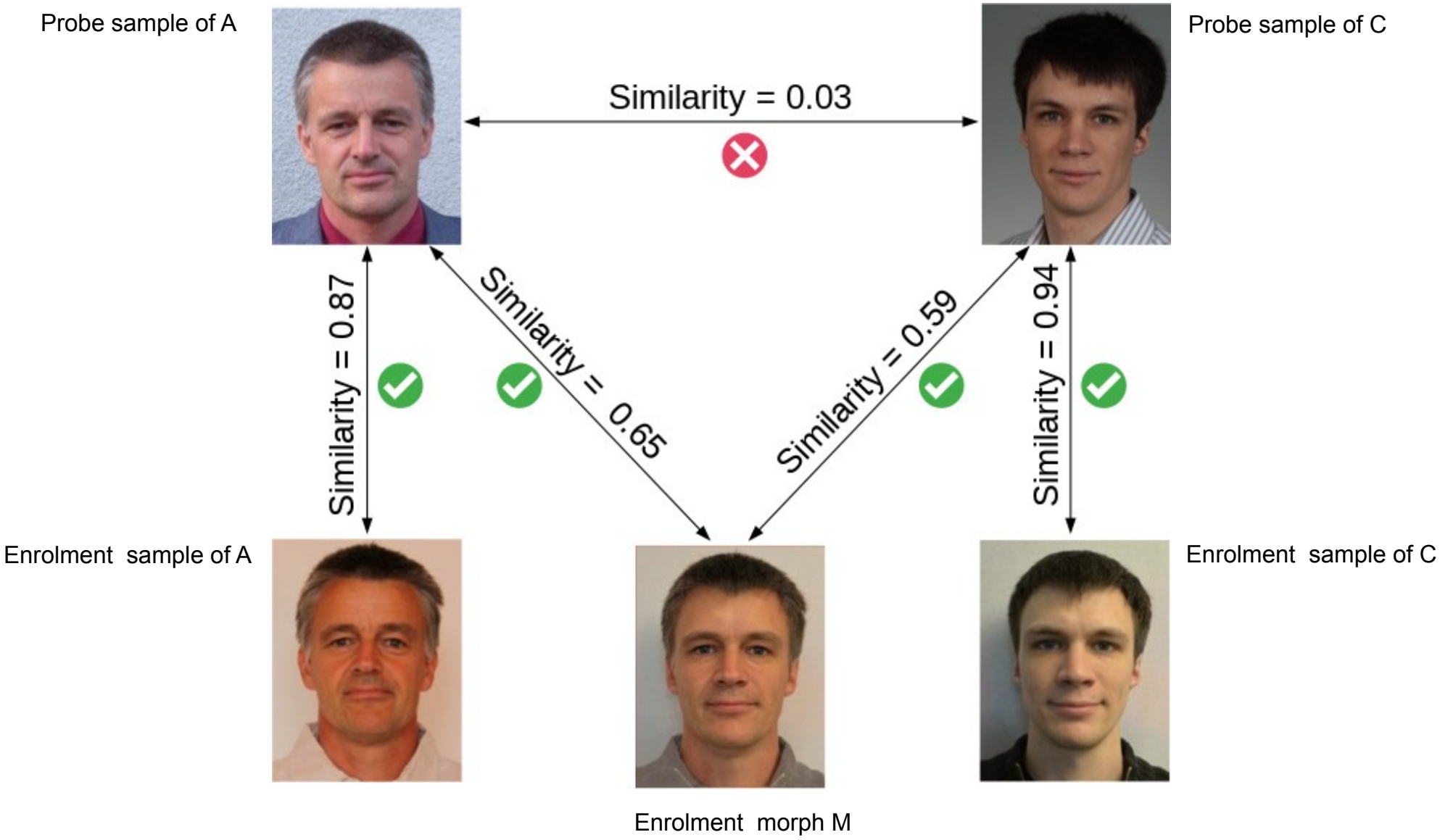
Problem: Morphing Attacks

Morphing attack scenario

- Border control

Problem: Morphing Attacks

Verification against morphed facial images



Problem: Morphing Attacks

Is it a really problem ?

Problem: Morphing Attacks

Is it a really problem ? - YES!

- In September 2018 German activists
  - used a morphed images of Federica Mogherini (High representative of the European Union for Foreign Affairs and Security Policy) and a member of their group
  - and received an authentic German passport.

Image source: https://www.spiegel.de/netzwelt/netzpolitik/biometrie-im-reisepass-peng-kollektiv-schmuggelt-fotomontage-in-ausweis-a-1229418.html

What is the vulnerability?

Scale of the Problem: Vulnerability

Human Experts Capabilities - (44 border guards)

[FFM2016] M. Ferrara, A. Franco, D. Maltoni: “On the Effects of Image Alterations on Face Recognition Accuracy”, in Face Recognition Across the Imaging Spectrum, Springer Nature, (2016)

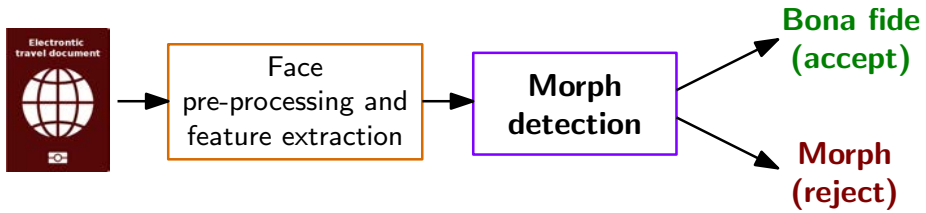
Morphing Attack Detection (MAD)

Scenarios and Methods

Morphing Attack Detection Scenarios

Real world scenarios

- Single image morphing attack detection (S-MAD)
  - One single *suspected* facial image is analysed (e.g. in the passport application)

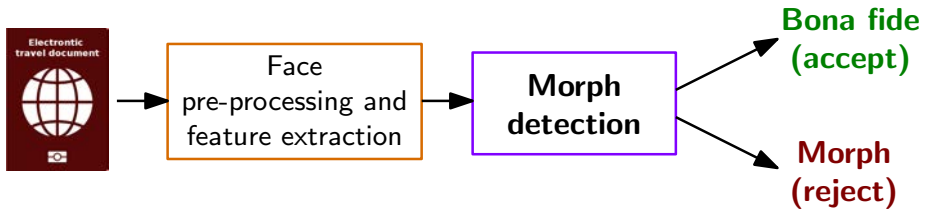


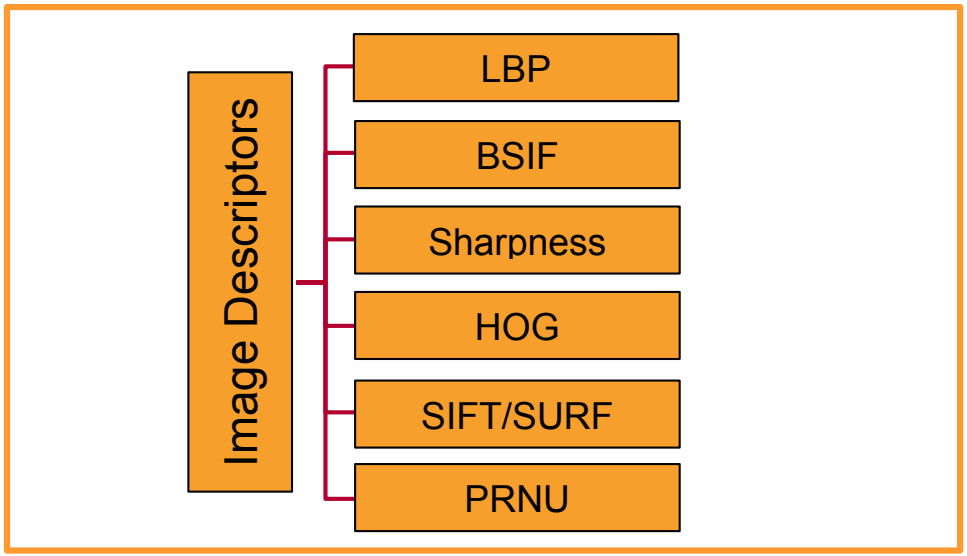
[SRB2018a] U. Scherhag, C. Rathgeb, C. Busch: "Towards Detection of Morphed Face Images in electronic Travel Documents“, in Proceedings of the 13th IAPR International Workshop on Document Analysis Systems (DAS), April 24-27, (2018)

Face Pre-processing and Feature Extraction

Morphing Attack Detection (S-MAD) with texture analysis

- Image descriptors as hand-crafted features





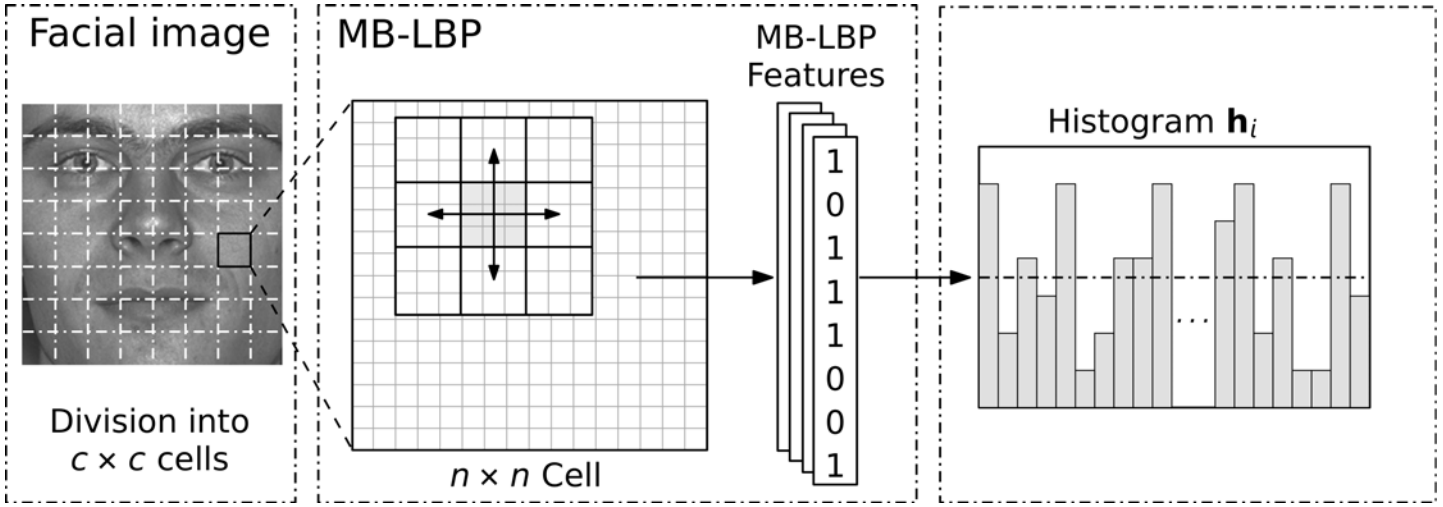
Morph Detection Classifier

[SRB2018b] U. Scherhag, C. Rathgeb, C. Busch: „Detection of Morphed Faces from Single Images: a Multi-Algorithm Fusion Approach“, in Proceedings if of the 2nd International Conference on Biometric Engineering and Applications (ICBEA), Amsterdam, The Netherlands, May 16-18, (2018)

Face Pre-processing and Feature Extraction

S-MAD with image descriptor

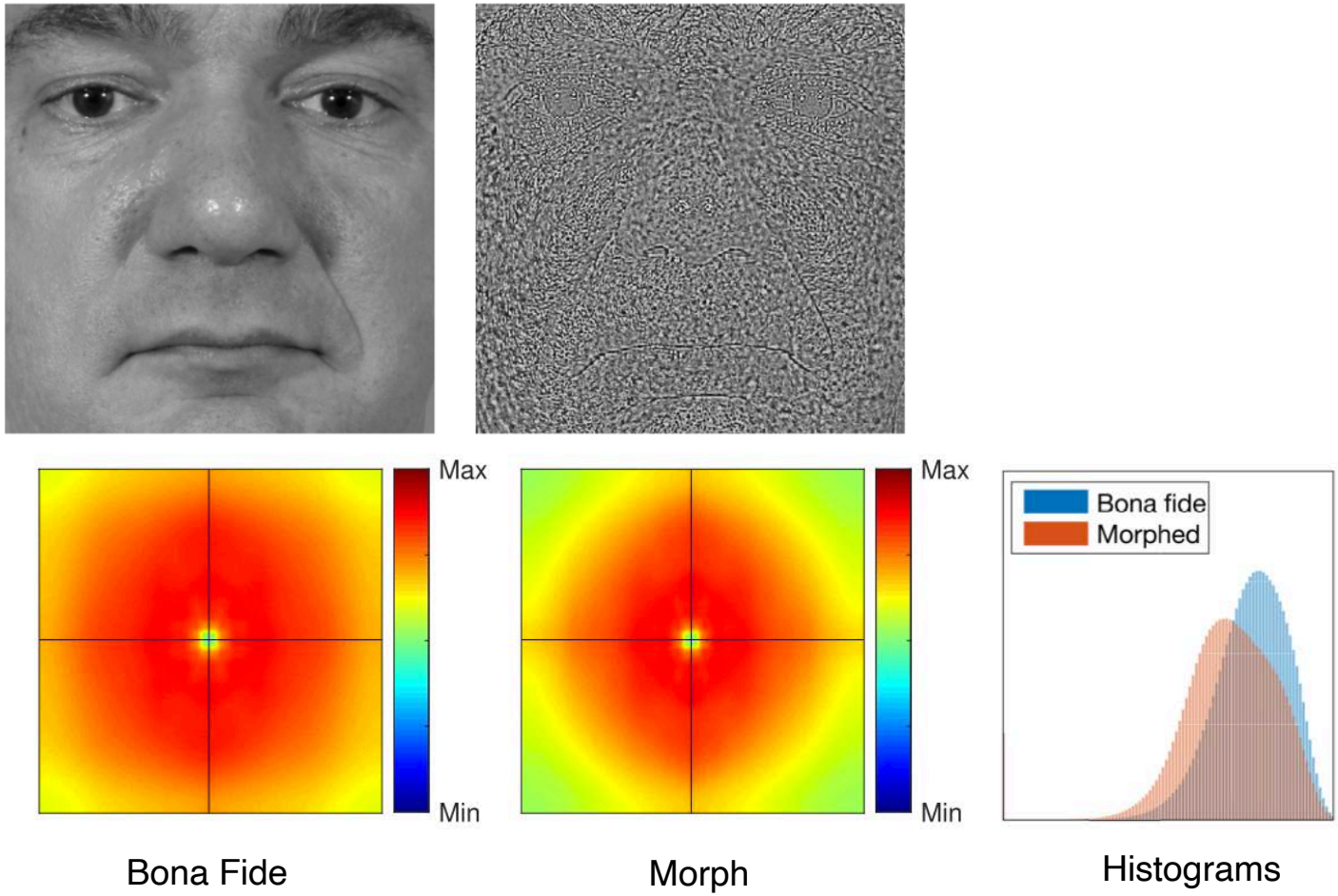
- Local Binary Pattern (LBP)



Face Pre-processing and Feature Extraction

S-MAD with image descriptor / forensic approach

- Photo Response Non-Uniformity (PRNU)

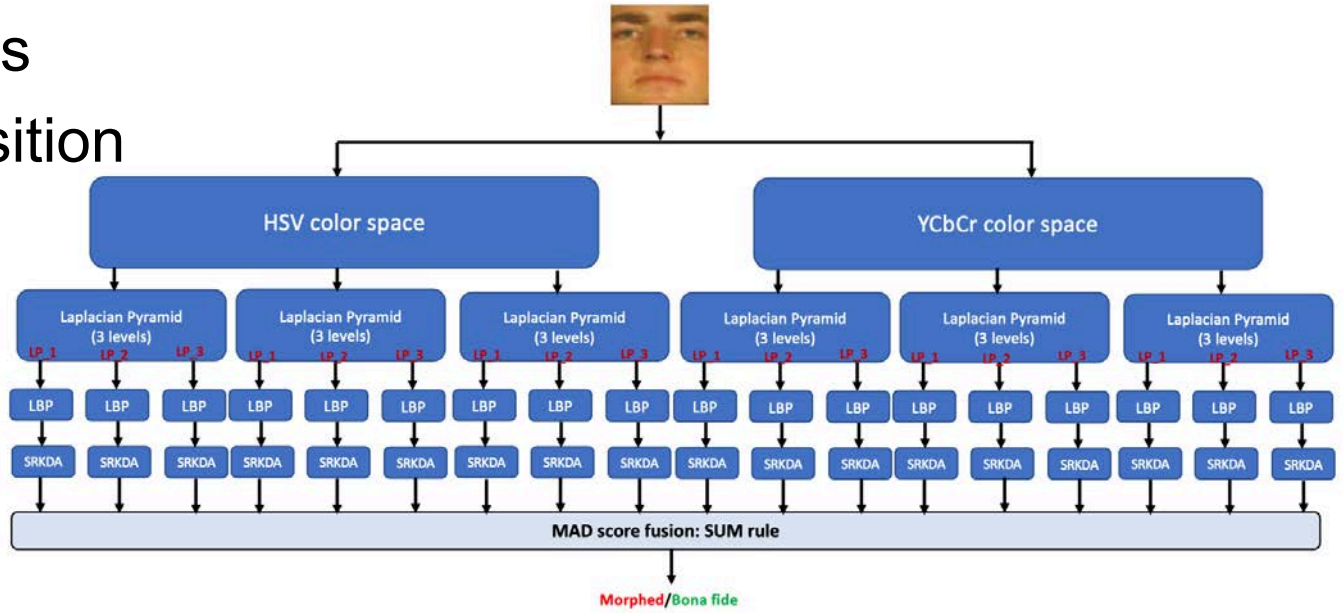


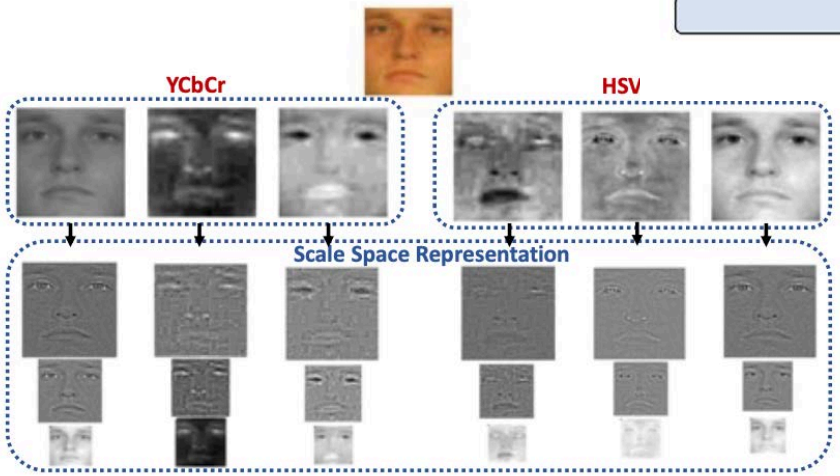
[SDRBU2019] U. Scherhag, L. Debiasi, C. Rathgeb, C. Busch and A. Uhl: "Detection of Face Morphing Attacks based on PRNU Analysis“, in IEEE TBIOM, (2019)

Face Pre-processing and Feature Extraction

S-MAD with Scale-Space features

- Transformation to different color spaces
- Laplacian decomposition



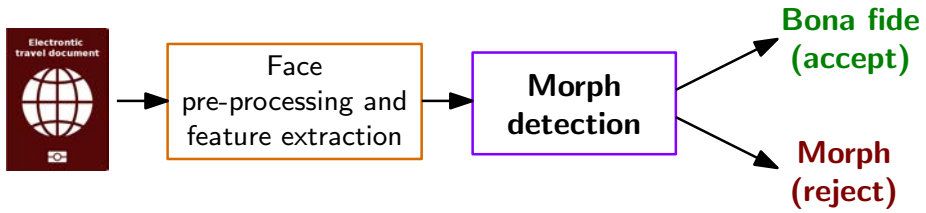


[RVRB2019] R. Raghavendra, S. Venkatesh, K. Raja, C. Busch: "Towards making Morphing Attack Detection robust using hybrid scale-space Colour Texture Features", in Proceedings of the International Conference on Identity, Security and Behavior Analysis (ISBA), (2019)

Face Pre-processing and Feature Extraction

Morphing Attack Detection (S-MAD) with texture analysis

- Image descriptors as Deep features



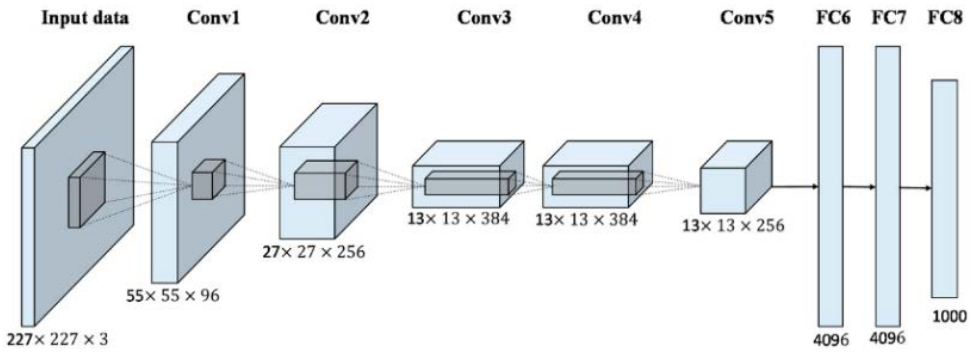
CNN BlackBox

Morph Detection Classifier

Face Pre-processing and Feature Extraction

S-MAD with deep learning

- Feature Representations
  - pre-trained Convolutional Neural Network (CNN)

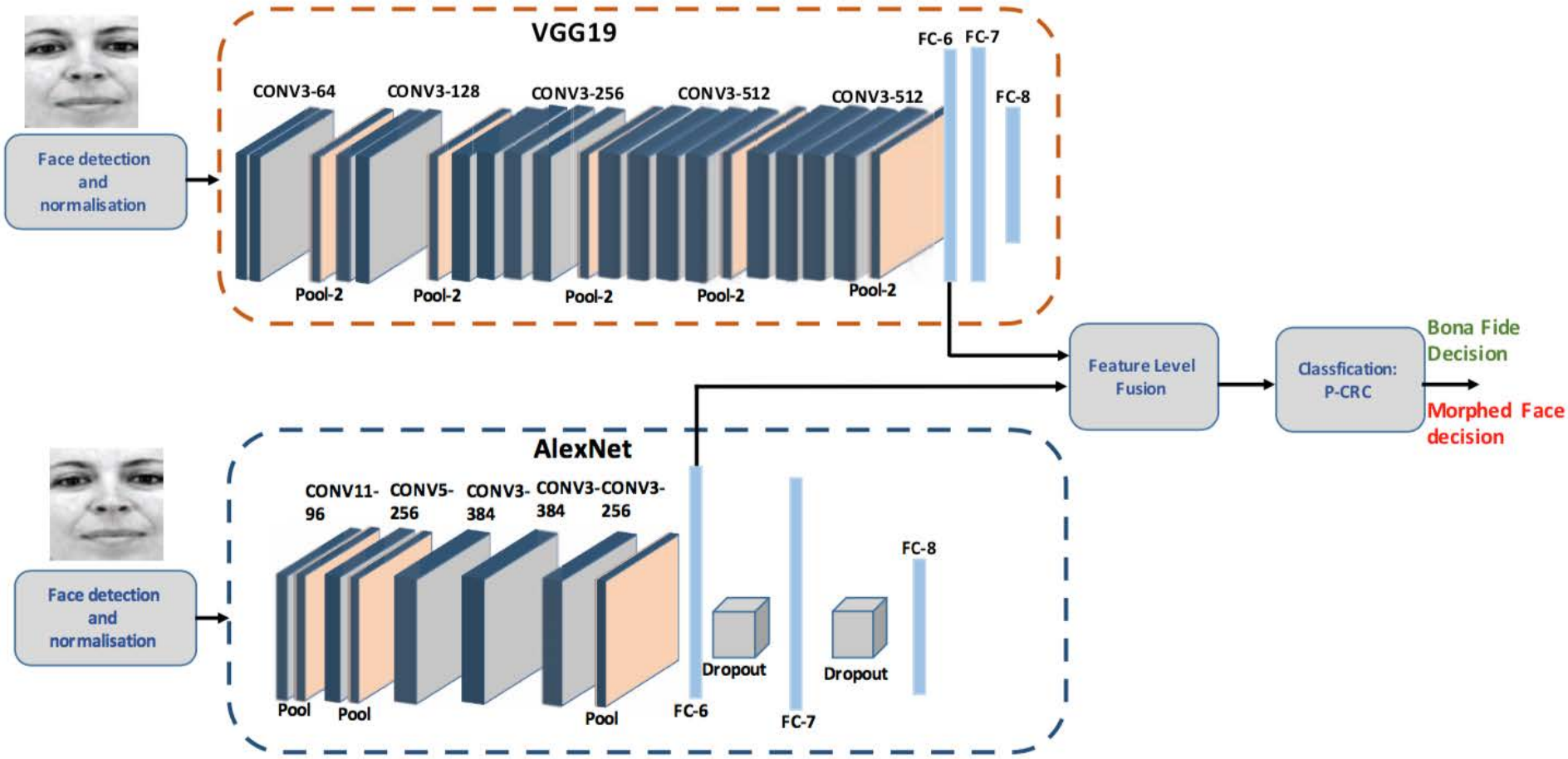


Morph Detection Classifier

Single Image Morphing Attack Detection

S-MAD with deep learning

- Feature level fusion of Deep CNNs

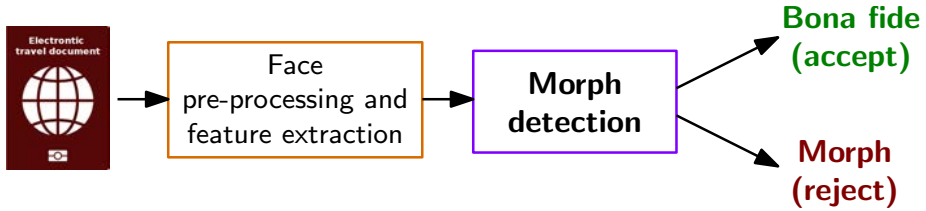


[RRVBu2017] R. Raghavendra, K. Raja, S. Venkatesh, C. Busch: "Transferable Deep-CNN features for detecting digital and print-scanned morphed face images", in Proceedings of 30th International Conference on Computer Vision and Pattern Recognition Workshop (CVPRW), July 21-26, (2017)

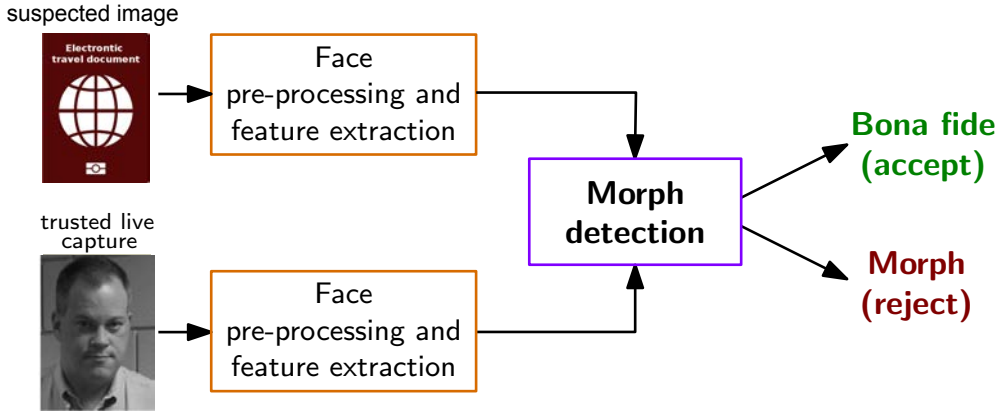
Morphing Attack Detection Scenarios

Real world scenarios

- Single image morphing attack detection (S-MAD)
  - One single *suspected* facial image is analysed (e.g. in the passport application)



- Differential morphing attack detection (D-MAD)
  - A pair of images is analysed - and one is a trusted Bona Fide image
  - Biometric verification (e.g. at the border)

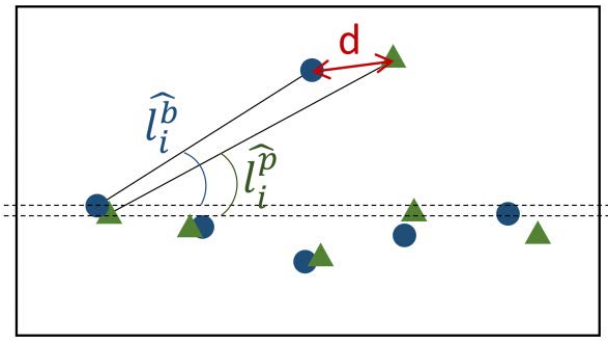


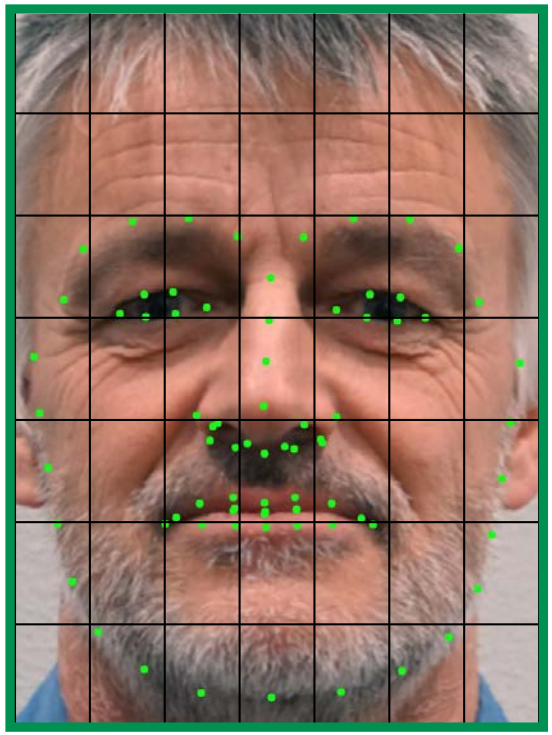
[SRB2018a] U. Scherhag, C. Rathgeb, C. Busch: "Towards Detection of Morphed Face Images in electronic Travel Documents", in Proceedings of the 13th IAPR International Workshop on Document Analysis Systems (DAS), April 24-27, (2018)

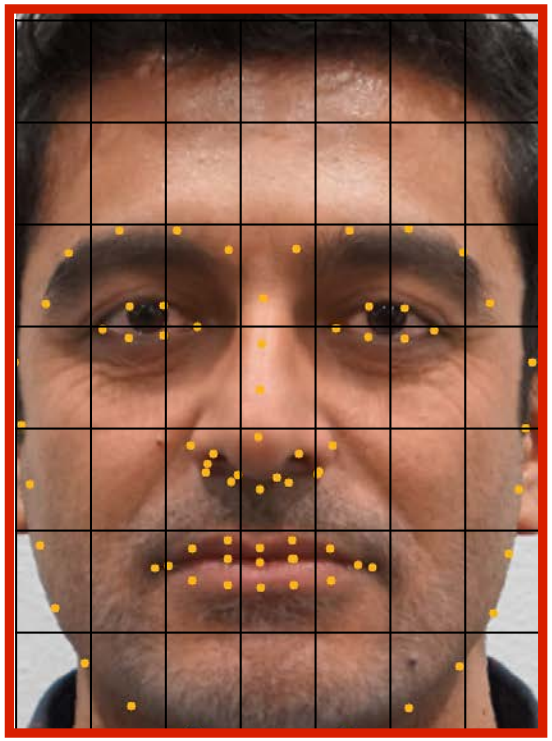
Differential Morphing Attack Detection

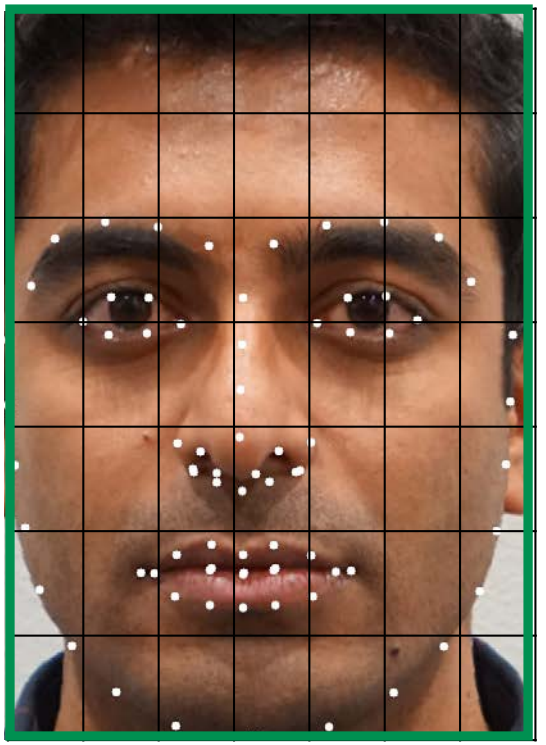
D-MAD with landmark analysis

- Angle based features
- Distance based features







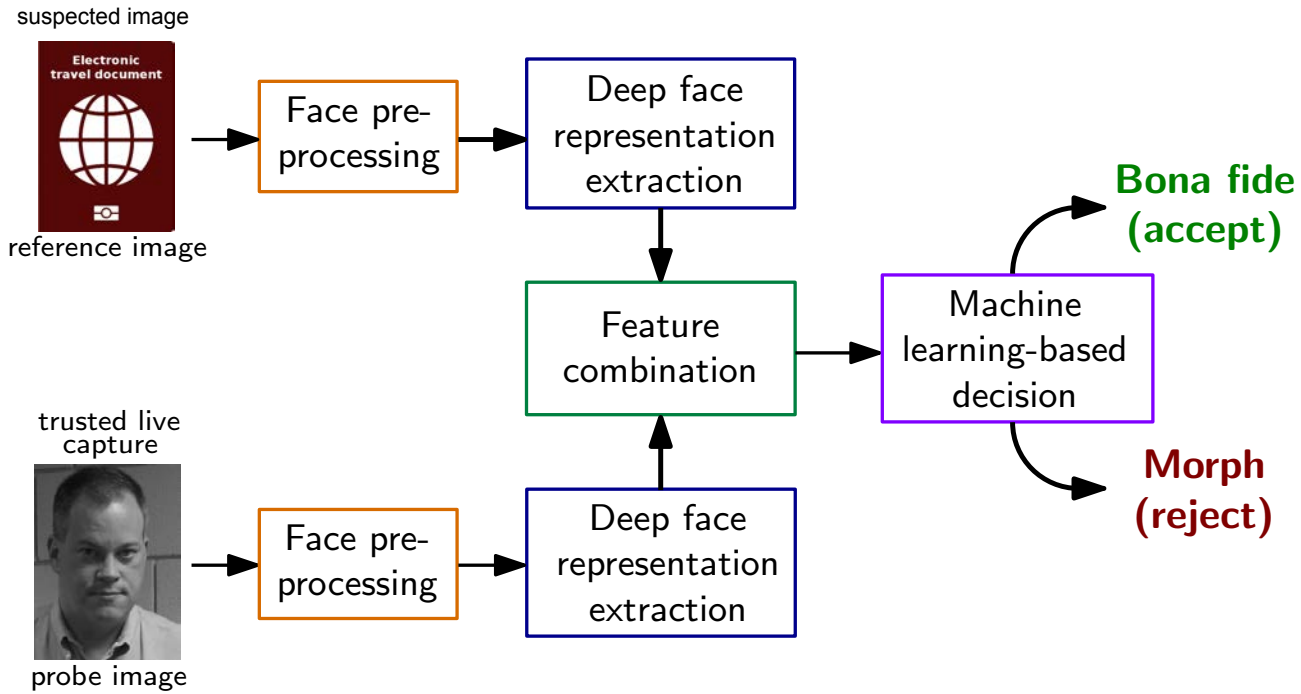


[SDGB2018] U. Scherhag, D. Budhrani, M. Gomez-Barrero, C. Busch: "Detecting Morphed Face Images Using Facial Landmarks“, in Proceedings of International Conference on Image and Signal Processing (ICISP), (2018)

Differential Morphing Attack Detection

D-MAD with deep learning

- Deep Face representations of Deep CNNs



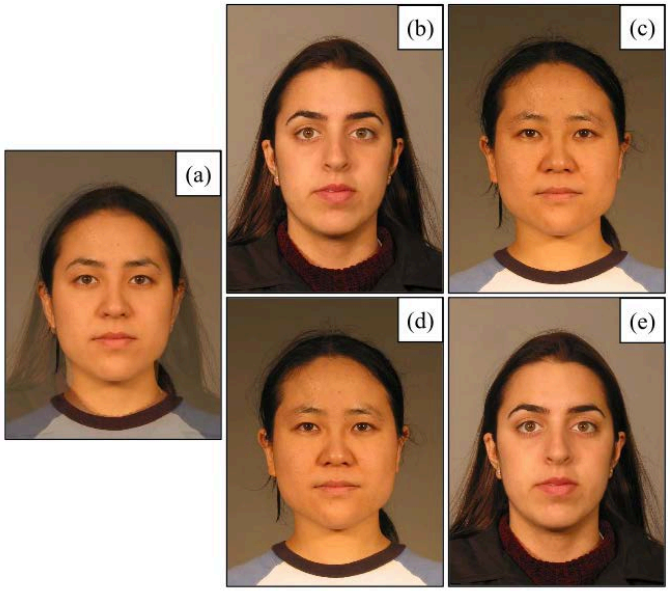
- Deep representations extracted by the neural network (on the lowest layer)
- Feature space with small dimension: 512 (for ArcFace)
- SVM with radial basis function

[SRMB2020] U. Scherhag, C. Rathgeb, J. Merkle, C. Busch: "Deep Face Representations for Differential Morphing Attack Detection", in IEEE Transactions on Information Forensics and Security (TIFS), (2020)

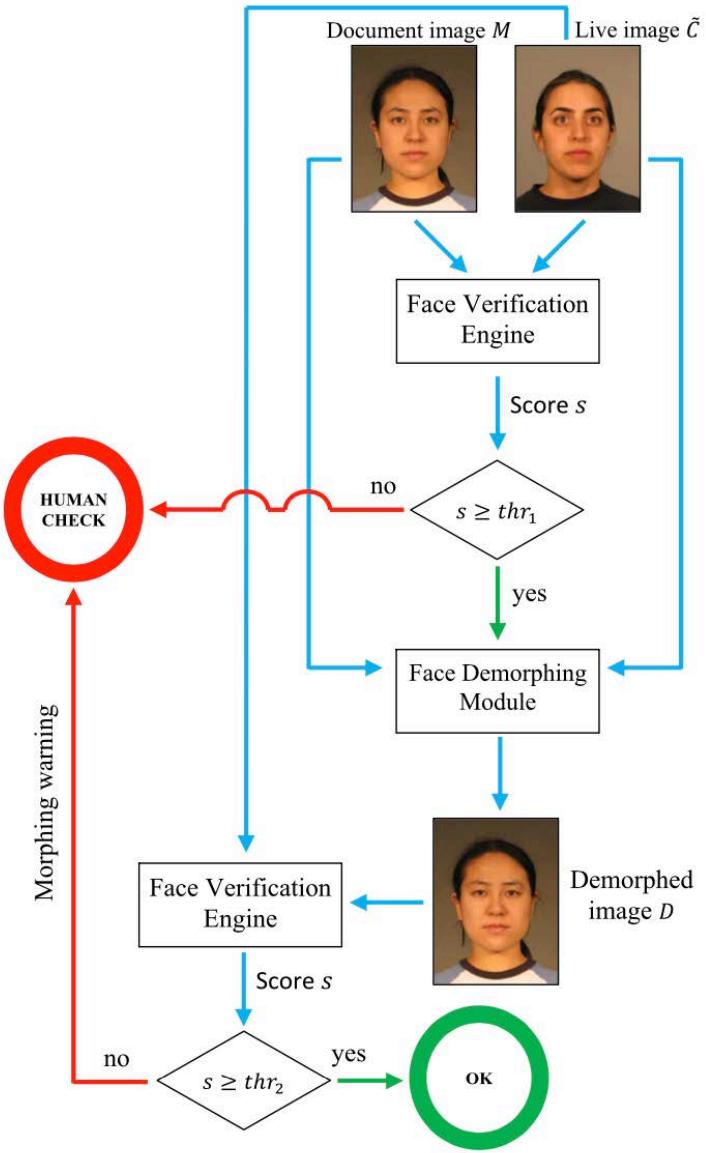
Differential Morphing Attack Detection

D-MAD with Demorphing

- Invert the morphing process
- Then confirm the similarity score



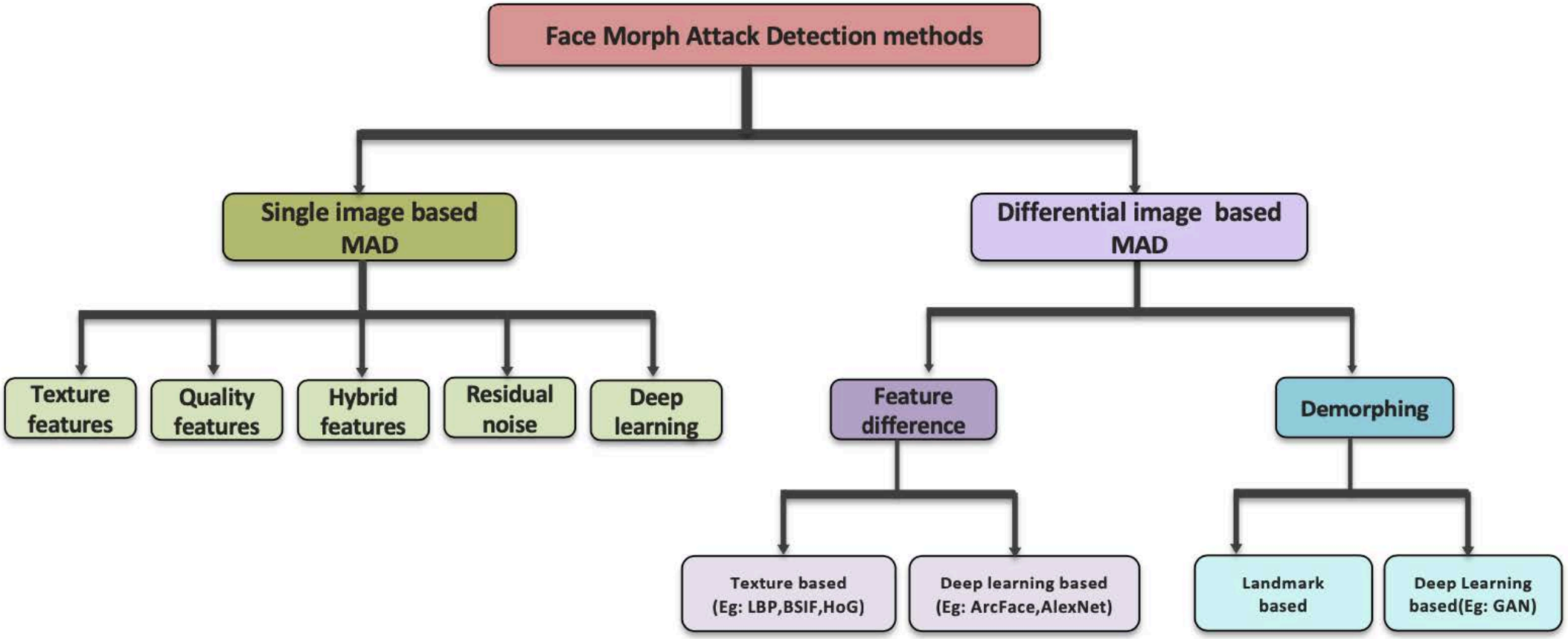
a) suspected image
b) and c): trusted live capture image
d) and e): recovery image



[Ferrara2018] M. Ferrara, A. Franco, D. Maltoni: "Face Demorphing“,
in IEEE Transactions on Information Forencics and Security (TIFS), (2018)

State of the Art - MAD Algorithms

Taxonomy of Morphing Attack Detection



[Venkatesh2021] S. Venkatesh, R. Raghavendra, K. Raja, C. Busch: "Face Morphing Attack Generation & Detection: A Comprehensive Survey", in IEEE Transactions on Technology and Society (TTS), (2021)

MAD Evaluation

Standardized Testing Metrics

Definition according to ISO/IEC 30107-3

- Testing the
  false-negative and false-positive errors:

- **Attack presentation classification error rate (APCER)**
  proportion of attack presentations using the same PAI species incorrectly classified as bona fide presentations in a specific scenario

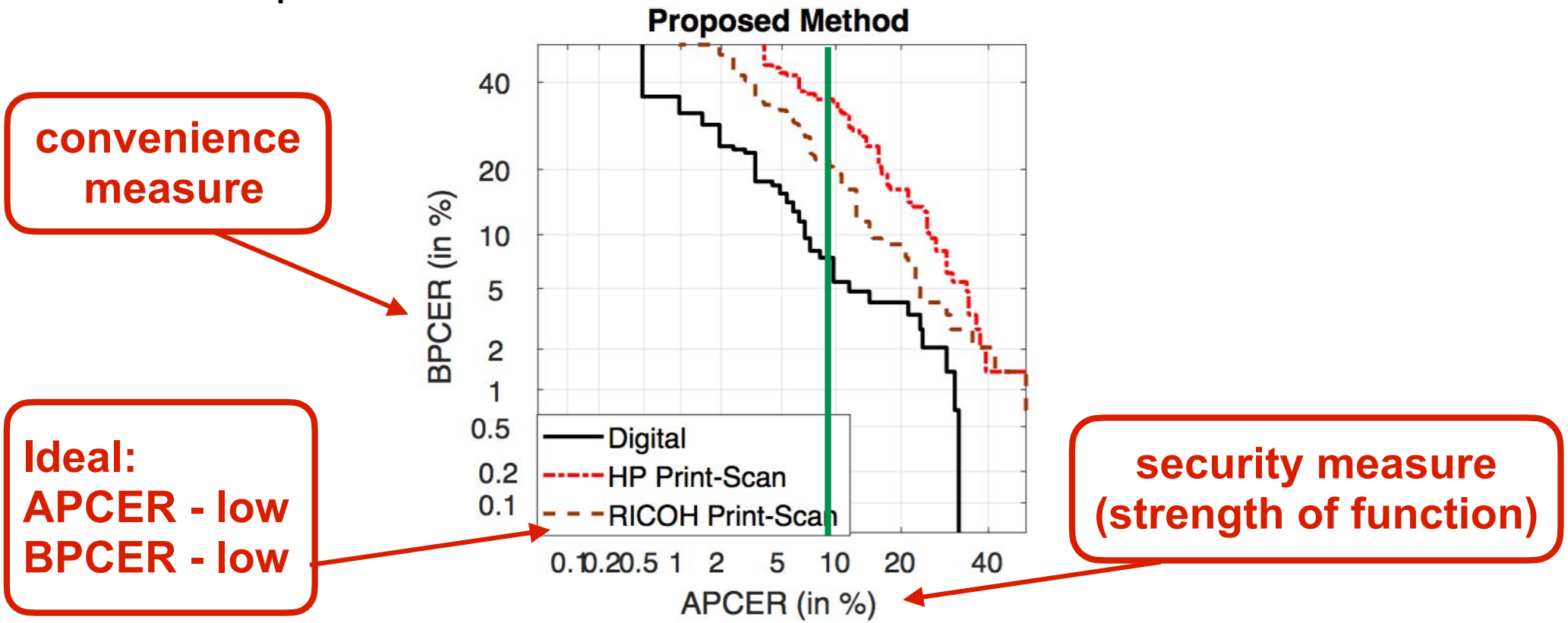
- **Bona fide presentation classification error rate (BPCER)**
  proportion of bona fide presentations incorrectly classified as attack presentations in a specific scenario

source: [ISO/IEC 30107-3] SO/IEC 30107-3, “Biometric presentation attack detection - Part 3: Testing and reporting”, (2017)
https://www.iso.org/standard/67381.html

Standardized Testing Metrics

Definition of metrics in ISO/IEC 30107-3

- DET curve analyzing operating points for various thresholds and plot security measures versus convenience measures
- Example:



Source: R. Raghavendra, K. Raja, S. Venkatesh, C. Busch: "Transferable Deep-CNN features for detecting digital and print-scanned morphed face images", in Proceedings of 30th International Conference on Computer Vision and Pattern Recognition Workshop (CVPRW 2017), Honolulu, Hawaii, July 21-26, (2017)

MAD Evaluation Methodology

Face Morphing Attack evaluations are complex

- Evaluations must consider a dedicated methodology [SNR2017]
- Evaluations must consider many parameters

$$result = f\,(dataset\text{-}training,\ dataset\text{-}testing,\ morphing\text{-}attack,\ landmark\text{-}detector,\ feature\text{-}extractor,\ classifier,\ scenario\ (S\text{-}MAD\ vs.\ D\text{-}MAD),\ post\text{-}processing,\ printer,\ scanner,\ ageing)$$

[SNR2017] U. Scherhag, A. Nautsch, C. Rathgeb, M. Gomez-Barrero, R. Veldhuis, L. Spreeuwers, M. Schils, D. Maltoni, P. Grother, S. Marcel, R. Breithaupt, R. Raghavendra, C. Busch: "Biometric Systems under Morphing Attacks: Assessment of Morphing Techniques and Vulnerability Reporting", in Proceedings of the IEEE 16th International Conference of the Biometrics Special Interest Group (BIOSIG), Darmstadt, September 20-22, (2017)

MAD Evaluation in SOTAMD

EU funded project: February 2019 – January 2020

- Partners:
  - National Office for Identity Data, NL, Bundeskriminalamt (BKA), DE
  - University of Bologna (UBO), IT, Hochschule Darmstadt (HDA), DE
  - The University of Twente (UTW), NL, NTNU, NO



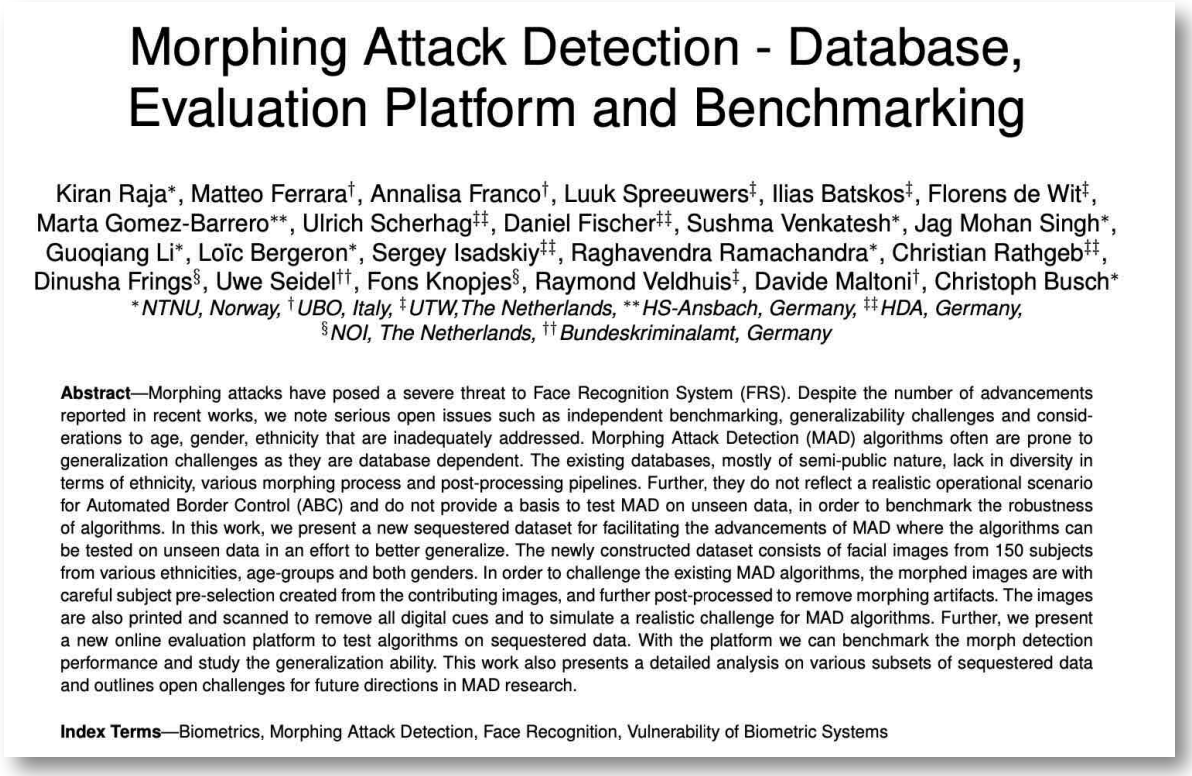

Specific objectives:

- Capture face images from 150 subjects
  - with photo equipment and automated border control gates
- Generate morphed face images with at least 3 algorithms
- Post-process automatically and manually
- Print and scan all morphed face images
- MAD Test on the Bologna-Online-Evaluation-Platform (BOEP)
  - Provide open access benchmark tests.
  - D-MAD evaluation:
    https://biolab.csr.unibo.it/FVCOnGoing/UI/Form/BenchmarkAreas/BenchmarkAreaDMAD.aspx

Research on Morphing Attack Detection

MAD Evaluation in SOTAMD

- SOTAMD dataset and testing platform
  https://ieeexplore.ieee.org/document/9246583



Morphing Attack Detection - Database, Evaluation Platform and Benchmarking

Kiran Raja*, Matteo Ferrara†, Annalisa Franco†, Luuk Spreeuwers‡, Ilias Batskos‡, Florens de Wit‡, Marta Gomez-Barrero**, Ulrich Scherhag‡‡, Daniel Fischer‡‡, Sushma Venkatesh*, Jag Mohan Singh*, Guoqiang Li*, Loïc Bergeron*, Sergey Isadskiy‡‡, Raghavendra Ramachandra*, Christian Rathgeb‡‡, Dinusha Frings§, Uwe Seidel††, Fons Knopjes§, Raymond Veldhuis‡, Davide Maltoni†, Christoph Busch*
*NTNU, Norway, †UBO, Italy, ‡UTW,The Netherlands, **HS-Ansbach, Germany, ‡‡HDA, Germany, §NOI, The Netherlands, ††Bundeskriminalamt, Germany

Abstract—Morphing attacks have posed a severe threat to Face Recognition System (FRS). Despite the number of advancements reported in recent works, we note serious open issues such as independent benchmarking, generalizability challenges and considerations to age, gender, ethnicity that are inadequately addressed. Morphing Attack Detection (MAD) algorithms often are prone to generalization challenges as they are database dependent. The existing databases, mostly of semi-public nature, lack in diversity in terms of ethnicity, various morphing process and post-processing pipelines. Further, they do not reflect a realistic operational scenario for Automated Border Control (ABC) and do not provide a basis to test MAD on unseen data, in order to benchmark the robustness of algorithms. In this work, we present a new sequestered dataset for facilitating the advancements of MAD where the algorithms can be tested on unseen data in an effort to better generalize. The newly constructed dataset consists of facial images from 150 subjects from various ethnicities, age-groups and both genders. In order to challenge the existing MAD algorithms, the morphed images are with careful subject pre-selection created from the contributing images, and further post-processed to remove morphing artifacts. The images are also printed and scanned to remove all digital cues and to simulate a realistic challenge for MAD algorithms. Further, we present a new online evaluation platform to test algorithms on sequestered data. With the platform we can benchmark the morph detection performance and study the generalization ability. This work also presents a detailed analysis on various subsets of sequestered data and outlines open challenges for future directions in MAD research.

Index Terms—Biometrics, Morphing Attack Detection, Face Recognition, Vulnerability of Biometric Systems

[Raja2020] K. Raja, M. Ferrara, A. Franco, L. Spreeuwers, I. Batskos, F. Wit, M. Gomez-Barrero, U. Scherhag, D. Fischer, S. Venkatesh, J. Singh, G. Li, L. Bergeron, S. Isadskiy, R. Raghavendra, C. Rathgeb, D. Frings, U. Seidel, F. Knopjes, R. Veldhuis, D. Maltoni, C. Busch: "Morphing Attack Detection - Database, Evaluation Platform and Benchmarking", in IEEE Transactions on Information Forensics and Security (TIFS), (2020)

NIST-FRVT-MORPH

NIST IR 8292 report presented April, 2021

FRVT-MORPH

https://pages.nist.gov/frvt/html/frvt_morph.html

- results for MAD algorithms from four research labs:
  - Hochschule Darmstadt (HDA)
  - Norwegian University of Science and Technology (NTNU)
  - University of Bologna (UBO)
  - University of Twente (UTW)

NISTIR 8292 DRAFT SUPPLEMENT

Face Recognition Vendor Test (FRVT)
Part 4: MORPH - Performance of Automated Face Morph Detection

Mei Ngan
Patrick Grother
Kayee Hanaoka
Jason Kuo
Information Access Division
Information Technology Laboratory

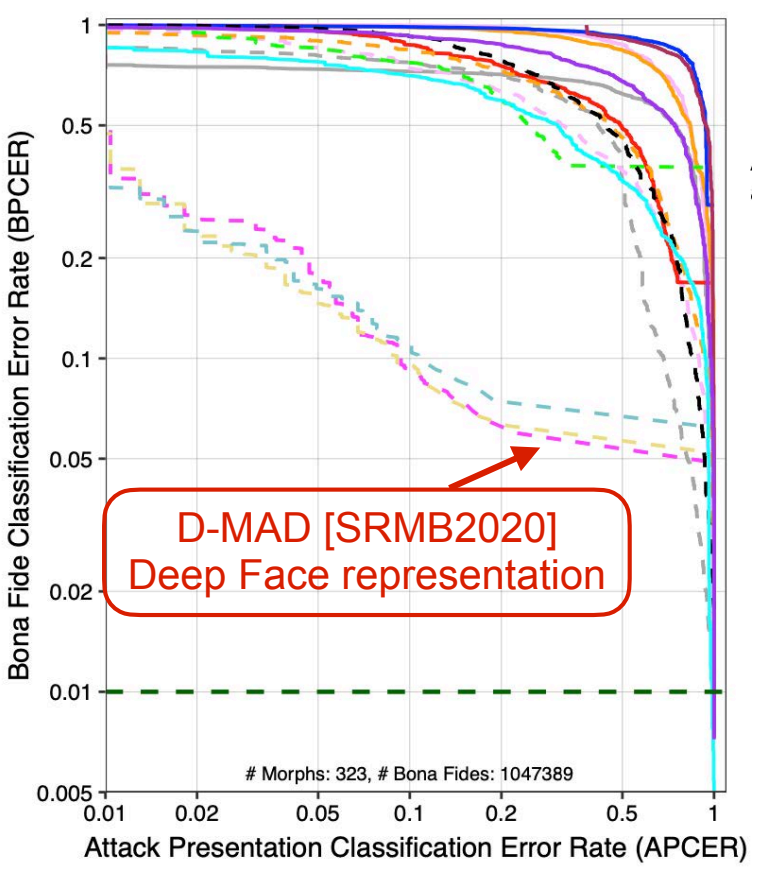
This publication is available free of charge from:
https://www.nist.gov/programs-projects/face-recognition-vendor-test-frvt-ongoing

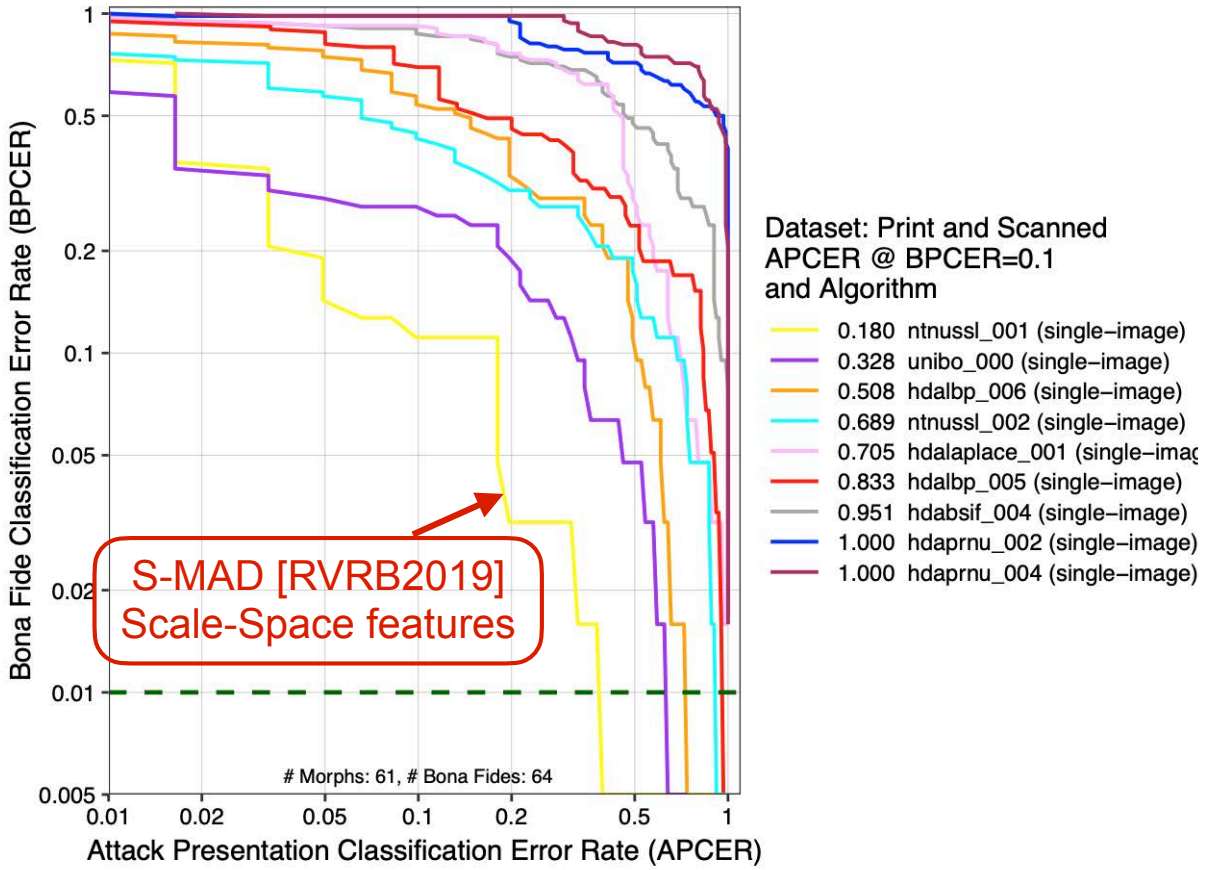
NIST
National Institute of Standards and Technology
U.S. Department of Commerce

NIST-FRVT-MORPH

NIST IR 8292 report presented April, 2021

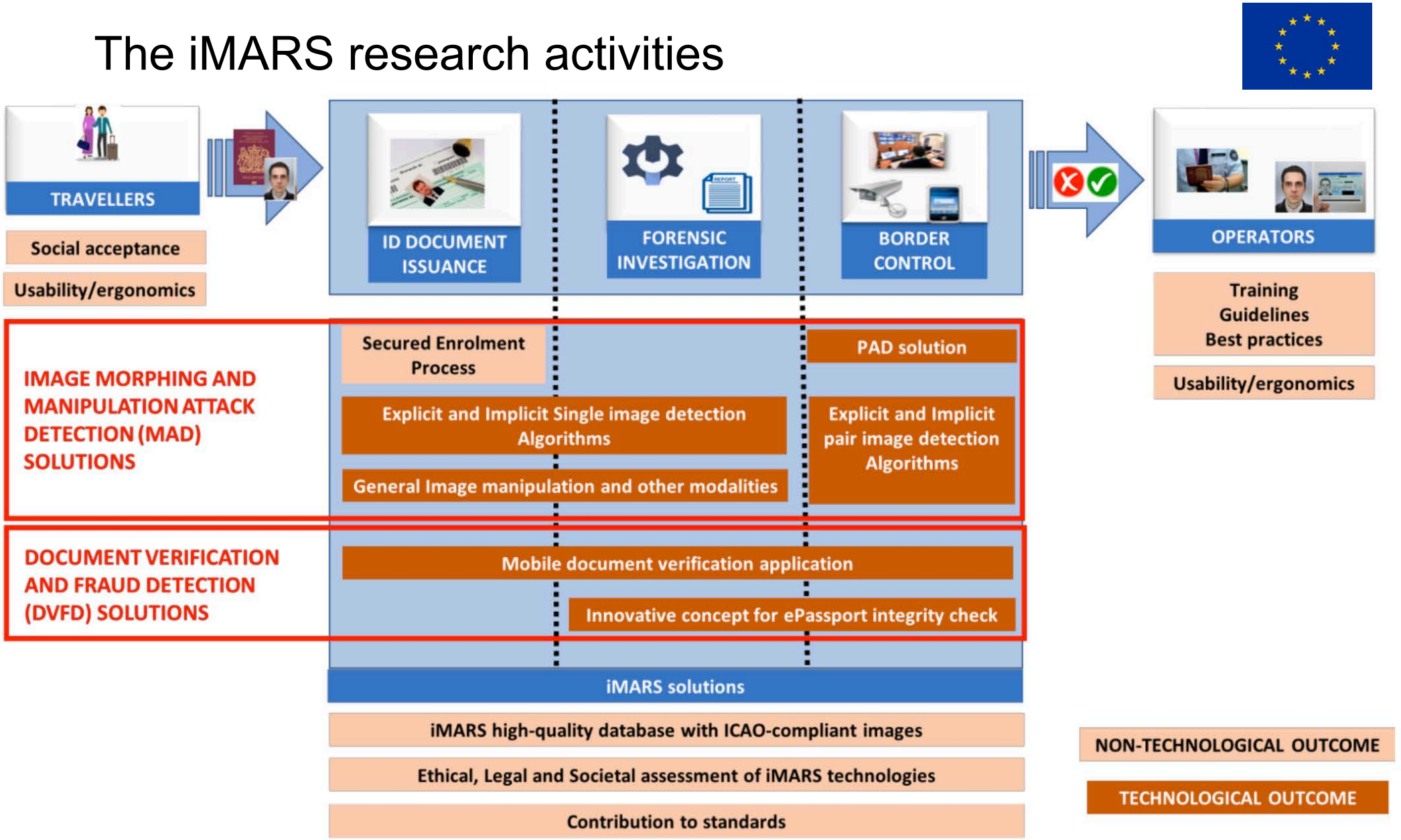
- Performance of Automated Face Morph Detection
  https://pages.nist.gov/frvt/reports/morph/frvt_morph_report.pdf
- results for high quality morphs versus print and scanned
  - note the low number of print and scanned images





Ongoing Research

The iMARS research activities



http://www.imars-project.eu/

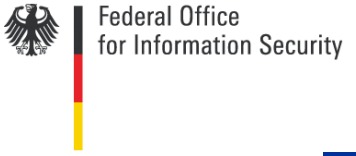
Thanks

I would like to thank the sponsors of this work:

- NGBS-Project funded by ATHENE

- SWAN-Project funded by RCN

- FACETRUST-Project funded by BSI



- SOTAMD-Project funded by
  the European Union's Internal Security Fund — Borders and Visa

- iMARS-Project has received funding from the
  European Union's H2020 research and innovation programme
  under grant agreement No 883356

  - The content of this presentation represents the views of the author only and is his sole responsibility.
    The European Commission does not accept any responsibility for use that may be made of the information it contains.

Conclusion

We are facing a situation, where

- Passports with morphs are already in circulation
  - 1000+ reported cases
  - Switch to live enrolment is a good decision, but does not solve the problem
- Passports with morphed face images will have a major impact on border security (introduction of EU's entry/exit system, global migration flows)
- In combination with passport brokers a dramatic problem
  - the darknet offers numerous such opportunities …

More information

The MAD website

https://www.christoph-busch.de/projects-mad.html

The MAD survey papers

- U. Scherhag, C. Rathgeb, J. Merkle, R. Breithaupt, C. Busch: "Face Recognition Systems under Morphing Attacks: A Survey“, in IEEE Access, (2019) https://ieeexplore.ieee.org/document/8642312


IEEE Access

Face Recognition Systems Under Morphing Attacks: A Survey

- S. Venkatesh, R. Raghavendra, K. Raja, C. Busch: "Face Morphing Attack Generation & Detection: A Comprehensive Survey", in IEEE Transactions on Technology and Society (TTS), (2021) https://ieeexplore.ieee.org/document/9380153


Face Morphing Attack Generation & Detection: A Comprehensive Survey

More information

The MAD workshop

https://eab.org/events/program/229

- Luuk Spreeuwers (University of Twente) - recorded talk
  - Morphing Attacks on Face Recognition Systems
- David Robertson (University of Strathclyde) - recorded talk
  - Psychological Experiments on Morphed Faces
- Kiran Raja (NTNU) - recorded talk
  - Morphing Attack Detection Approaches
- Matteo Ferrara (University of Bologna) - recorded talk
  - Bologna Online Evaluation Platform
- Frøy Løvåsdal (Norwegian Police) - recorded talk
  - Morphing Attack Detection Capabilities of Human Examiners
- Mei Ngan (NIST) - recorded talk
  - Face Morphing Detection Evaluation
- Naser Damer (Fraunhofer IGD) - recorded talk
  - Generating Morphs with Generative Adversarial Networks
- Christian Rathgeb (Hochschule Darmstadt) - recorded talk
  - Detection of Face Beautification Manipulations
- Uwe Seidel (BKA)
  - Research Needs for Morphing Attack Detection

More Information

European Association for Biometrics (EAB)

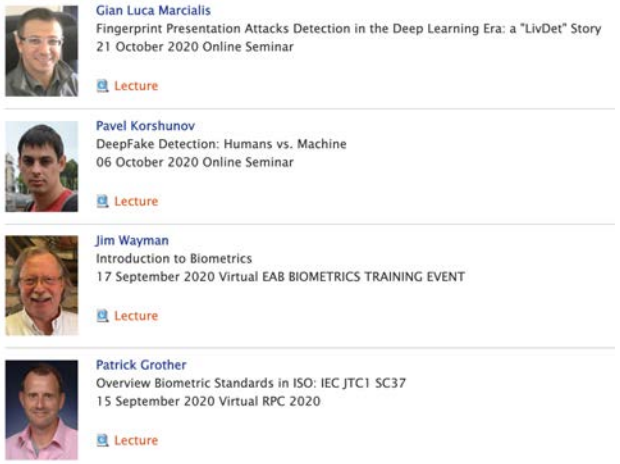
- The EAB is a non-profit, nonpartisan association
  https://eab.org/
- EAB supports all sections of the ID community across Europe, including governments, NGO's, industry, associations and special interest groups and academia.

- Our role is to promote the responsible use and adoption of modern digital identity systems that enhance people's lives and drive economic growth.
- Free membership for PhD students!
  https://eab.org/membership/types_of_membership.html

More Information

European Association for Biometrics (EAB)

- Our initiatives are designed to foster networking
  - Annual conference: EAB-RPC
    https://eab.org/events/program/195
  - Biometric Training Event
    https://eab.org/events/program/208
  - Workshops on relevant topics (e.g. Presentation Attack Detection, Morphing Attack Detection, Sample Quality, Bias in Biometric Systems)
    https://eab.org/events/
  - Online Seminar every second week
    https://eab.org/events/program/227
  - Recorded keynote talks
    https://eab.org/events/lectures.html
  - Monthly newsletter
    https://eab.org/news/newsletter.html
  - Annual academic graduation report
    https://eab.org/upload/documents/1799/EAB-research-report-2019.pdf
  - Open source repository
    https://eab.org/information/software.html



Thanks

I would like to thank my colleagues working on this topic:

- In the NBL - HDA research group:
  - Kiran Raja, Raghu Ramachandra, Loic Bergeron, Guoqiang Li
    Jag Mohan Singh, Sushma Venkatesh, Haoyu Zhang
  - Ulrich Scherhag, Christian Rathgeb, Daniel Fischer, Siri Lorenz
    Sergey Isadskiy, Marta Gomez-Barrero, Juan Tapia, Mathias Ibsen
- In the FACETRUST-Project:
  - Ralph Breithaupt, Johannes Merkle
- In the SOTAMD-Project and iMARS-Project:
  - Dinusha Frings, Fons Knopjes, Uwe Seidel,
  - Davide Maltoni, Matteo Ferrara, Analisa Franco
  - Raymond Veldhuis, Luuk Spreeuwers,
- In the NIST-FRVT-MORPH-Project:
  - Mei Ngan, Patrick Grother

Contact

Research opportunities

- Darmstadt (Germany) https://dasec.h-da.de/
- Gjøvik (Norway) https://www.ntnu.edu/nbl
- Internships for Msc and PhD students with possibility of a grant
- Collaboration with governmental and industrial partners