Face Image Quality and Demographic Variability

2026-05-06

Christoph Busch
copy of slides available at:
https://christoph-busch.de/about-talks-slides.html

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ATHENE

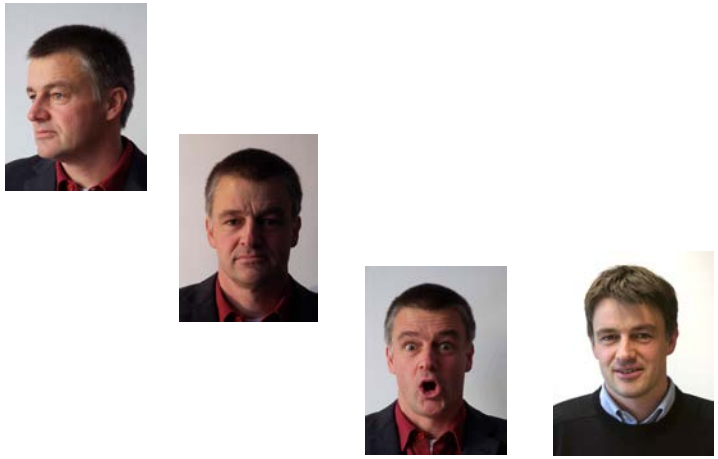
European Association for Biometrics eab Human Identity in Europe

NTNU

Challenges for Face Recognition

Critical factors for Face Recognition Systems (FRS):

- Pose
- Illumination
- Expression and Ageing



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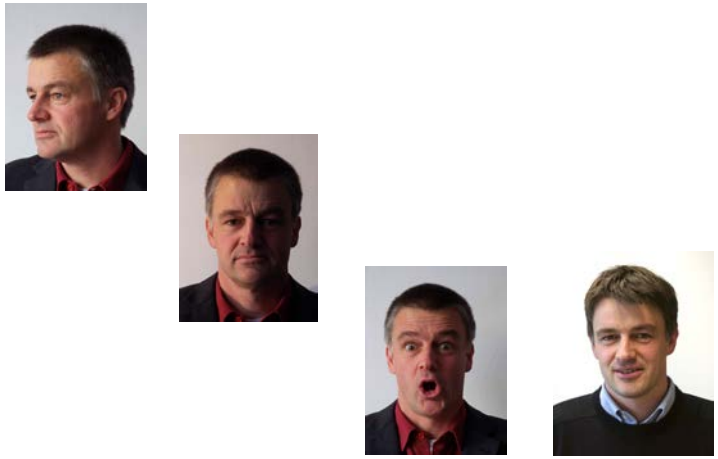
Challenges for Face Recognition

Critical factors for Face Recognition Systems (FRS):

- Pose
- Illumination
- Expression and Ageing
- Presentation Attacks



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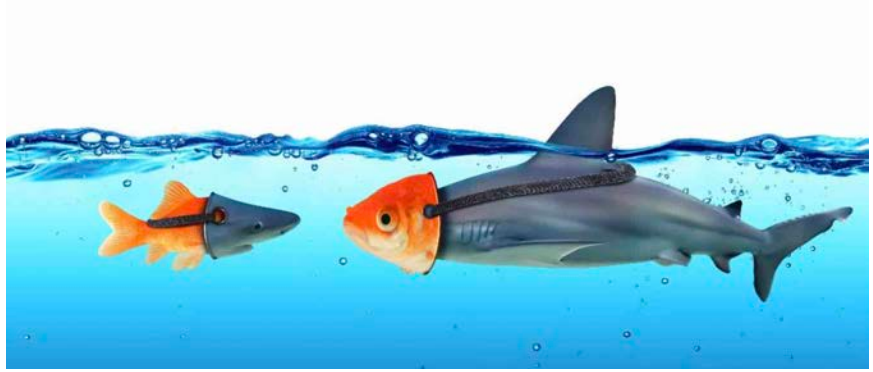

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Critical factors for Face Recognition Systems (FRS):

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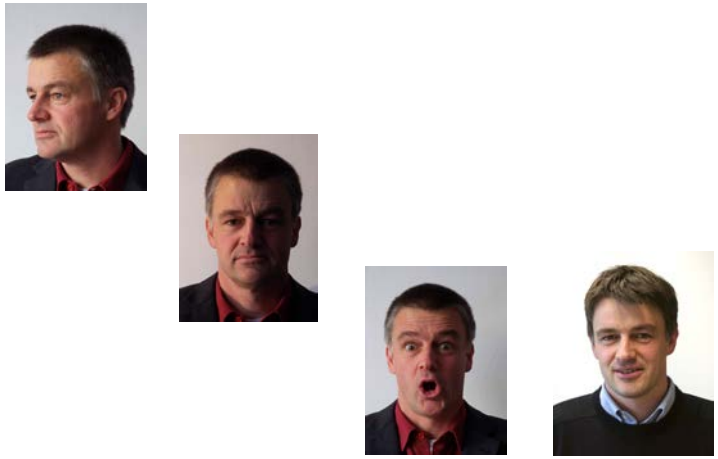
- Presentation Attacks
- Face Image Quality



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Challenges for Face Recognition

Critical factors for Face Recognition Systems (FRS):

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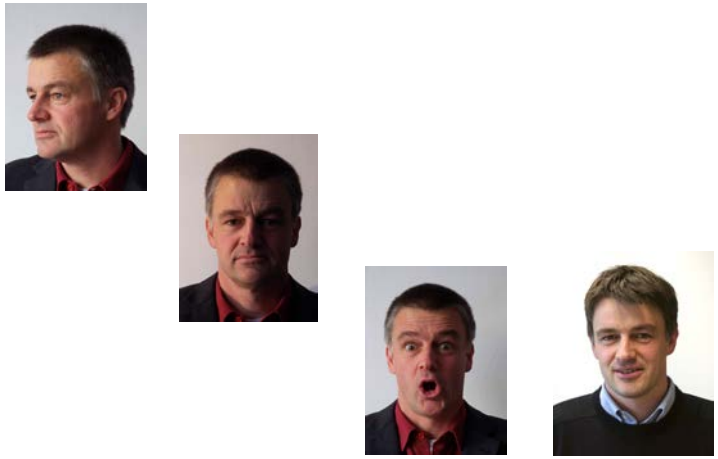
- Presentation Attacks
- Face Image Quality
- Morphing Attack Detection



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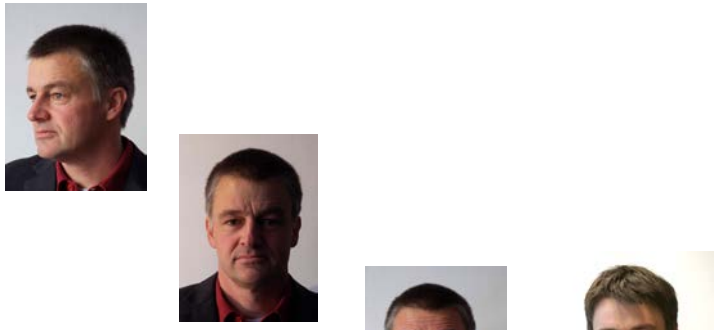

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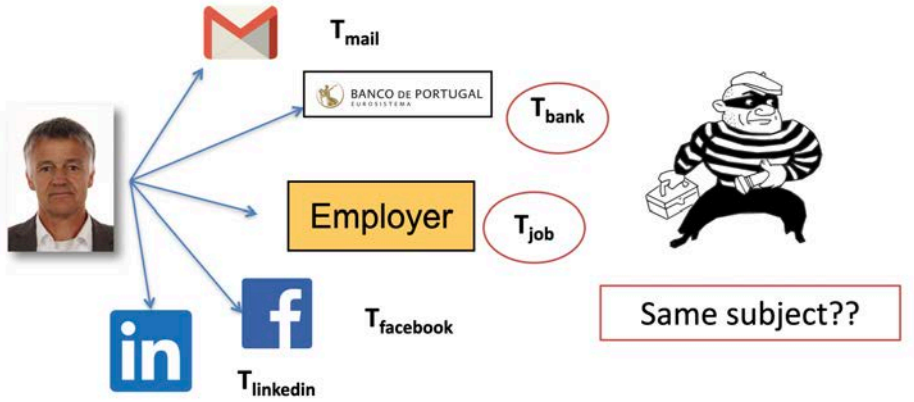

Challenges for Face Recognition

Critical factors for Face Recognition Systems (FRS):

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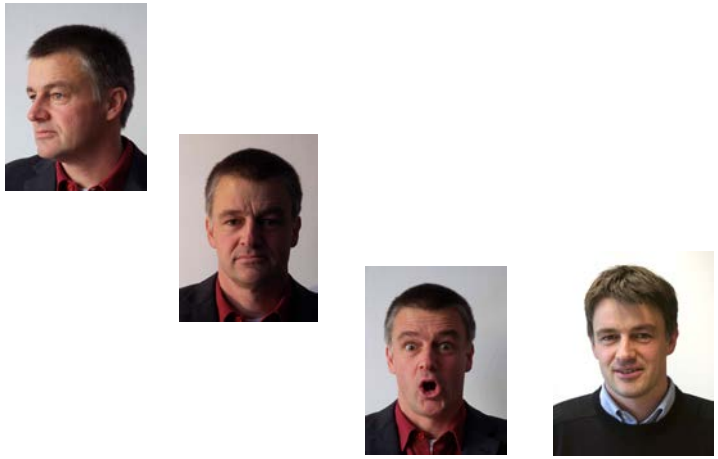
- Face Image Quality
- Morphing Attack Detection
- Biometric Template Protection
- Fairness of Algorithms



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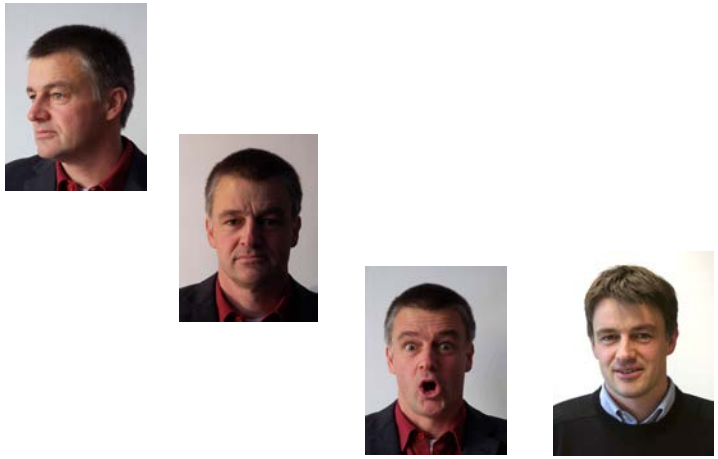
- Fairness of Algorithms
- Face Recognition with 1KB Reference



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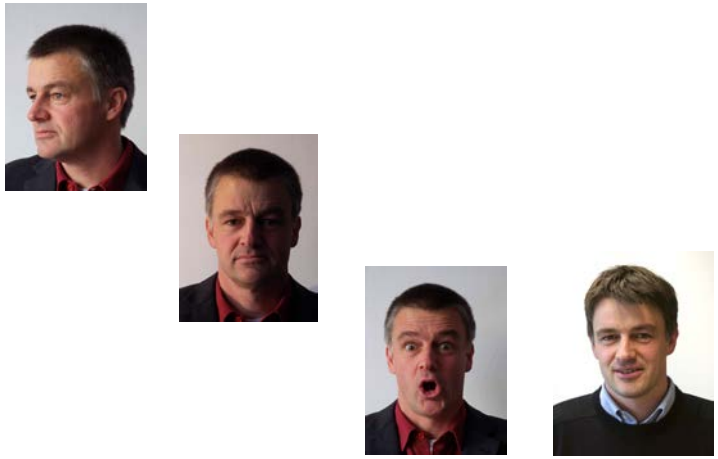

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Face Image Quality

Face Image Quality

Motivation for Face Image Quality Assessment (FIQA)

- Quality matters, especially in large-scale databases and with diverse application scenarios.
  - The European Entry Exit System (EES) started 12th October 2025
    - Applied to all external Schengen borders
    - Central register to record all entries/exists to the Schengen area
      https://travel-europe.europa.eu/ees_en

    - For each traveller a record with facial image and fingerprint images
    - Operated by eu-LISA and 29 countries

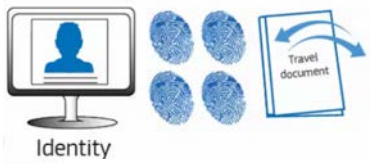


Image Source: eu-LISA

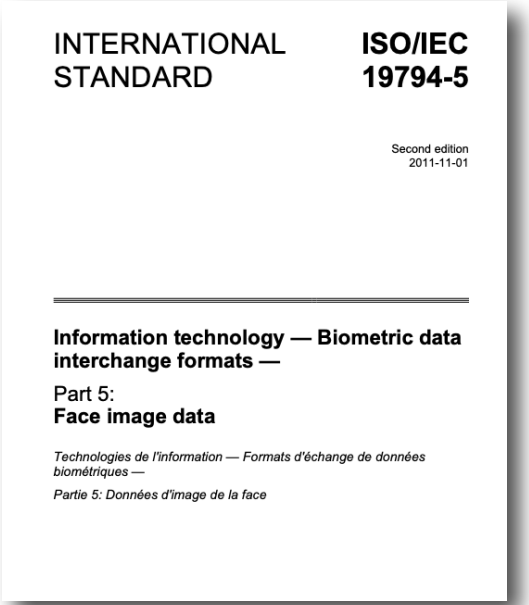
- Standardisation of minimal quality and harmonisation is essential for (semantic) interoperability.

Quality Requirements for Facial Images

The requirement in EES implementing decision 2019/329

- *„The quality of the facial images, … and with the image requirements of ISO/IEC 19794-5:2011 Frontal image type*

What does that mean?


INTERNATIONAL STANDARD

ISO/IEC 19794-5

Second edition
2011-11-01

Information technology — Biometric data interchange formats —

Part 5:
Face image data

Technologies de l'information — Formats d'échange de données biométriques —

Partie 5: Données d'image de la face

Data subjects need actionable feedback

- If quality is poor, then what went wrong?

Compliant image | Pose | Eyes open | Mouth open | Inhomogenous background

Source: ISO/IEC 39794-5

Measures for Facial Images

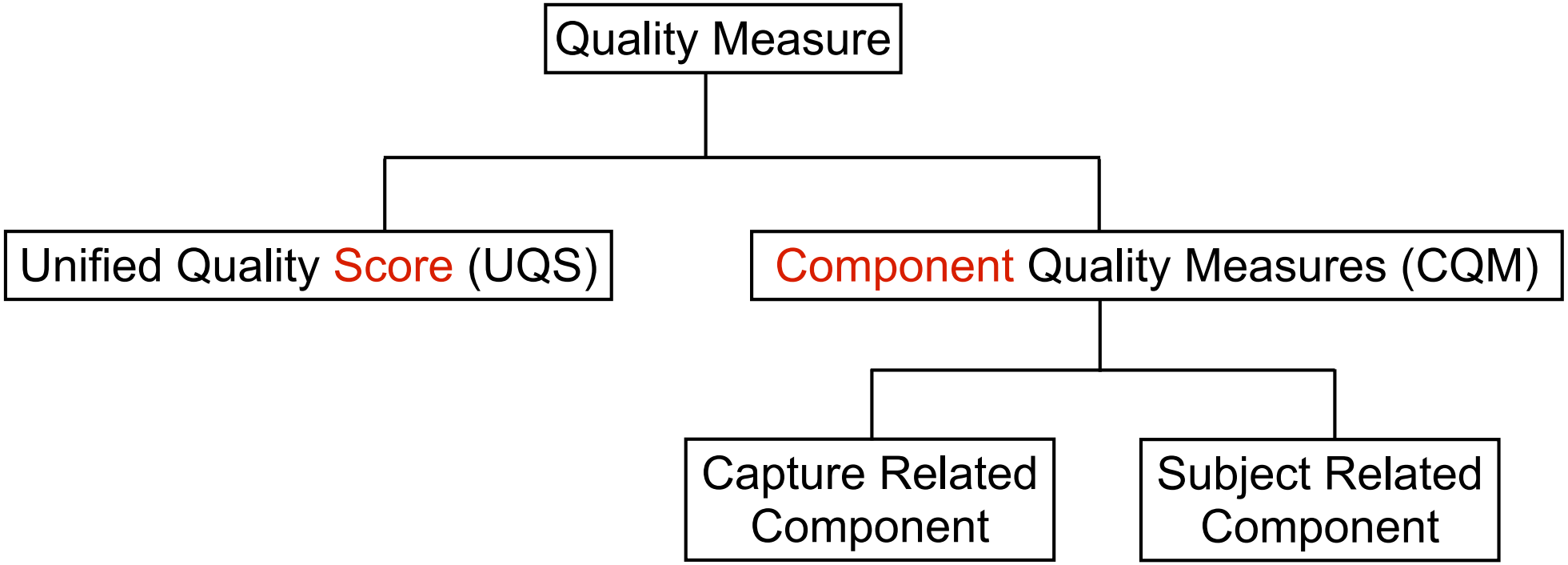
How to develop face image quality measures

- Standardisation
- International Organization for Standardization, ISO/IEC 29794-5, Information technology - Biometric sample quality - Part 5: Face image data,
  https://www.iso.org/standard/81005.html
  - Providing measures for requirements from ISO/IEC 19794-5:2011 and ISO/IEC 39794-5:2019
    - Use-1: Reference image for MRTD
    - Use-2: Reference image for Live-Enrolment at EES Kiosk
    - Use-3: Probe images (e.g. ABC gate)

Quality Measures - Framework Standard

Quality assessment algorithms

- According ISO/IEC 29794-1
  https://www.iso.org/standard/79519.html



- Higher UQS and CQM imply higher biometric utility

ISO/IEC 29794-5: Face Image Quality

ISO/IEC 29794-5 quality measures in detail

#	Face image quality measure
1.	Quality score (unified)
2.	Background uniformity
3.	Illumination uniformity
4.	Luminance mean
5.	Luminance variance
6.	Under-exposure prevention
7.	Over-exposure prevention
8.	Dynamic range
9.	Sharpness
10.	No compression artefacts
11.	Natural colour
12.	Single face present
13.	Eyes open
14.	Mouth closed
15.	Eyes visible
16.	Mouth occlusion prevention
17.	Face occlusion prevention
18.	Inter-eye distance
19.	Head size
20.	Leftward crop of face in image
21.	Rightward crop of face in image
22.	Margin above face in image
23.	Margin below face in image
24.	Pose angle yaw frontal alignment
25.	Pose angle pitch frontal alignment
26.	Pose angle roll frontal alignment
27.	Expression neutrality
28.	No head covering

Image Source:ISO/IEC 29794-5

Unified Quality Score

Capture device related

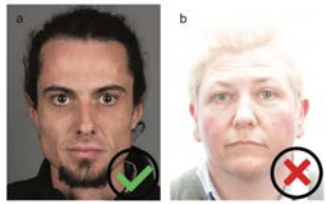


Image Source: ISO/IEC 39794-5

Explainable Quality Assessment

Subject related

Image Source: ISO/IEC 39794-5

OFIQ - Unified Quality Score

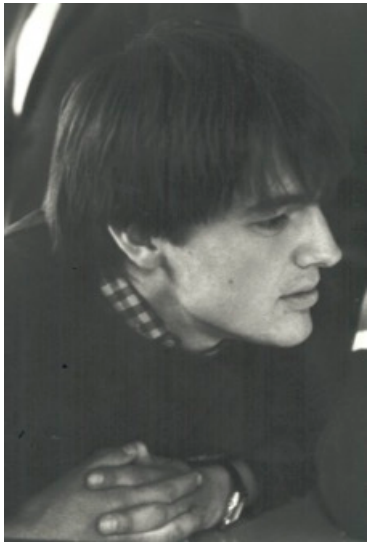
General, holistic unified quality score (OFIQ-UQS)

- Determine an overall quality score for the face image
  - CNN MagFace (iResNet 50 model)
- Shows good prediction of face recognition scores

OFIQ-UQS=84

OFIQ-UQS=61

OFIQ-UQS=26

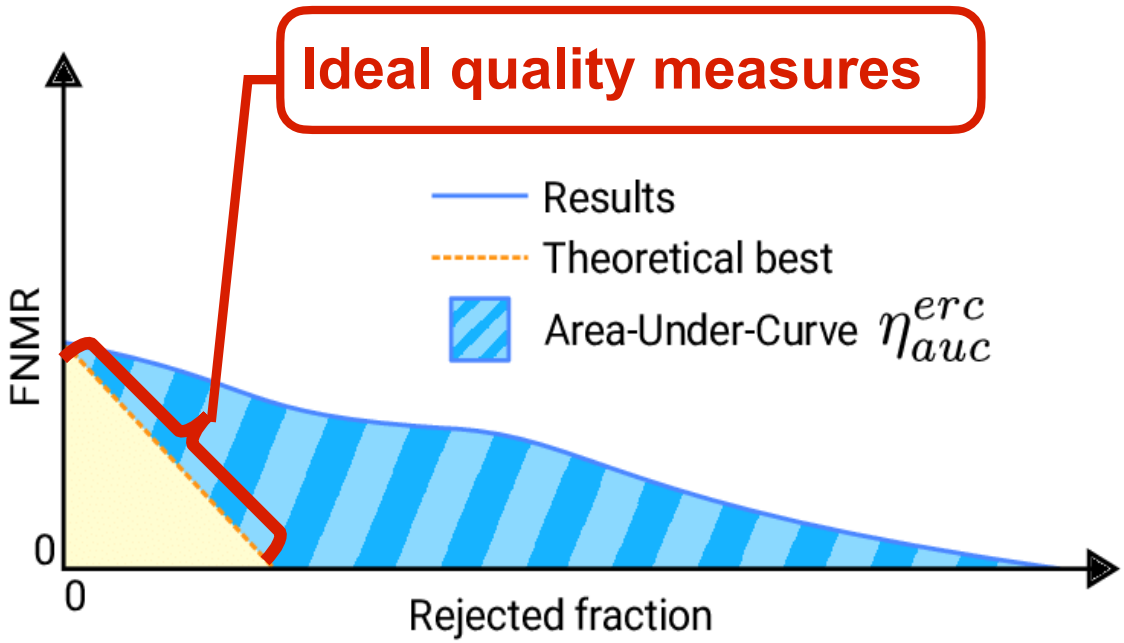


OFIQ-UQS=7

OFIQ - Unified Quality Score

Prediction of low face recognition scores

- OFIQ is the best performing algorithm in NIST SIDD Error versus Discard Characteristic (EDC) curves
  - How much is the FNMR reduced, when poor images are discarded/rejected?



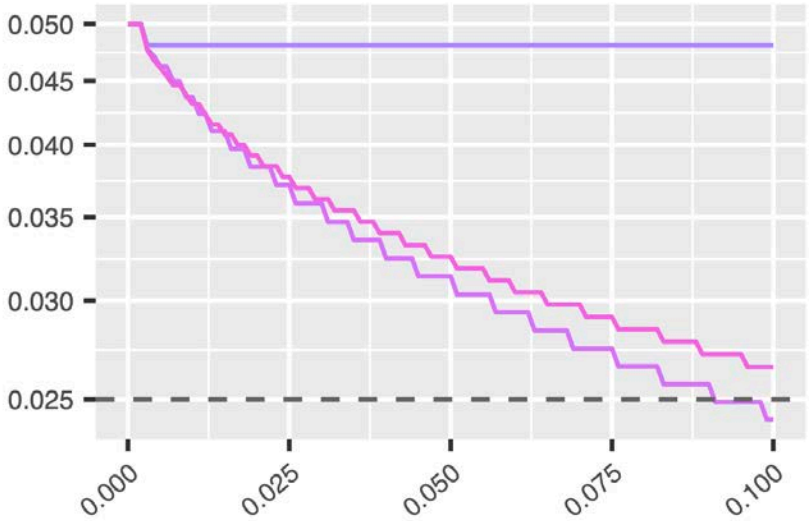


Image Source:NIST FATE SIDD report

Face Image Quality - Future work

Open research tasks for OFIQ 2

- Further innovation of quality measures
- Add missing components
  - Motion blur
  - Gaze estimation
  - …

Image Source: ISO/IEC 39794-5 Annex D1

- Investigate demographic variability

Fairness of Algorithms

Image Source: https://www.flaticon.com (2020)

Fairness of Biometric Algorithms

What is fairness?

- Dictionary:
  "*the quality of treating people equally or in a way that is right or reasonable*"

Movie Coded Bias - Image Source: Netflix

An inherently ethical and social concept

- Influenced by cultural, historical, legal, religious, personal, and other factors
- Everyone wants to be treated "fairly"

Reaching out towards group fairness

- Demographic groups: gender, age, skin tone, glasses etc.

Fairness of Biometric Algorithms

Possible Consequences of unfair algorithmic (and human) decision systems

- Differential treatment
  - **Definition**: *different set of actions for a biometric enrolee or biometric capture subject based on their demographic group*
    https://www.iso.org/obp/ui/en/#iso:std:iso-iec:19795:-10:ed-1:v1:en
- Unintentional discrimination
- Individual and collective social harms
  - social stigmatisation (e.g. Uigur people in China)

Demographic Factors in Biometrics

Measure and report

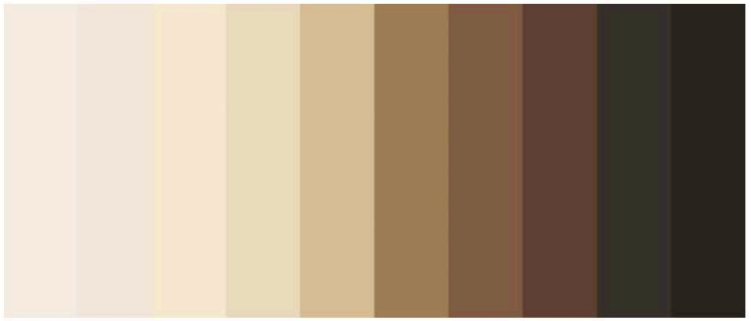
- Demographic differentials
  - **Definition**: *extent of difference in outcome of a biometric system across socially recognized sectors of the population*
    https://www.iso.org/obp/ui/en/#iso:std:iso-iec:2382:-37:ed-3:v1:en:term:37.09.28
- Demographic variables
  - gender
  - age
  - glasses
  - skin tone

Fitzpatrick Skin Types Image Source: HSBRS, (2016)

Face Image Quality - Demographics

Research tasks

- Investigate demographic variability (DV) of quality measures
- Skin tone variation is a continuous demographic variable
- Transformation to discrete categories
  - Monk skin tone scale (MST) vs.
  - Colorimetric skin ton (CST) vs.
  - PANTONE Skin Tone (PST)

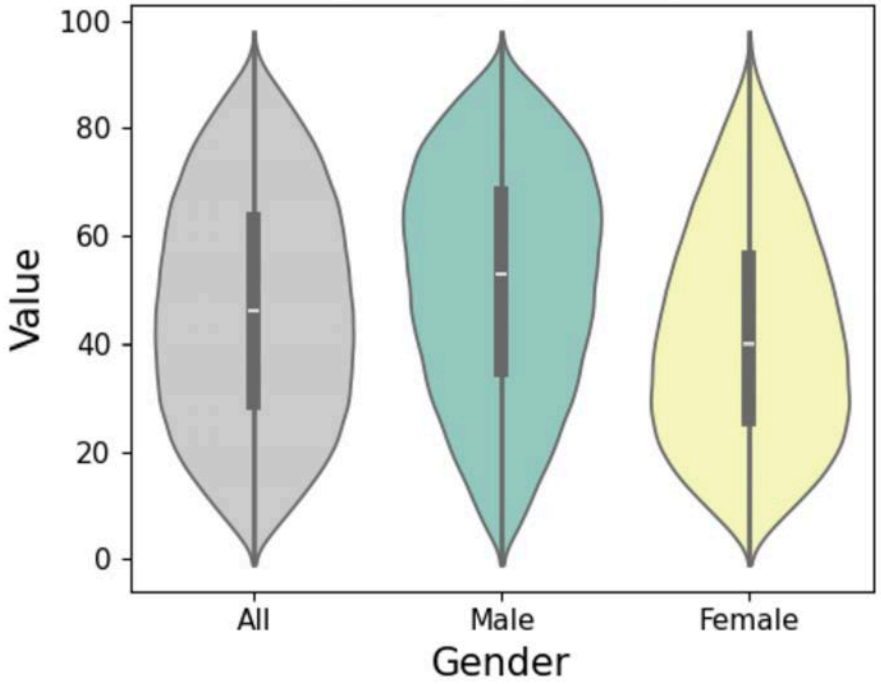


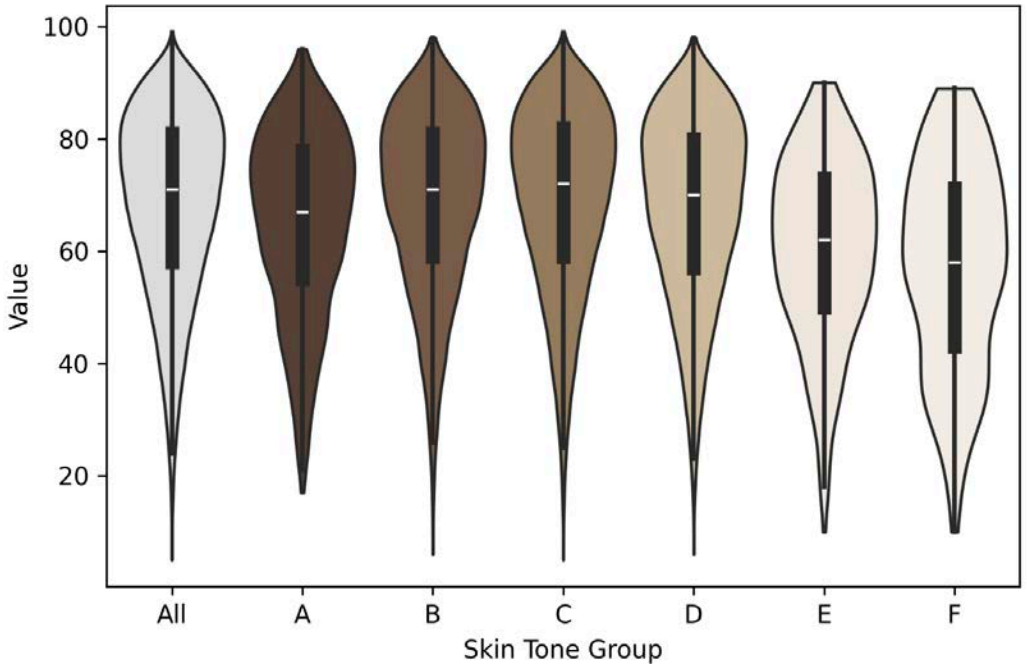
Face Image Quality - Demographic Variability

Research tasks

- Investigate variability across demographic groups
  - Distribution of unified quality score (UQS)

Demographic groups		UC1	UC3
Gender	Female	57,133	90,199
	Male	52,391	81,884
Age Group	0–20	5,169	7,534
	20–30:	24,576	37,802
	30–40:	27,878	46,140
	40–50:	18,710	29,702
	50+:	33,191	50,905
Skin Tone	A	1,308	1,410
	B	15,994	16,519
	C	51,954	55,126
	D	38,894	47,104
	E	384	419
	F	240	291
Origin	Africa	39	485
	America	4,616	7,360
	Asia	56,052	99,934
	Europe	45,050	58,435
	Oceania	3,765	5,866



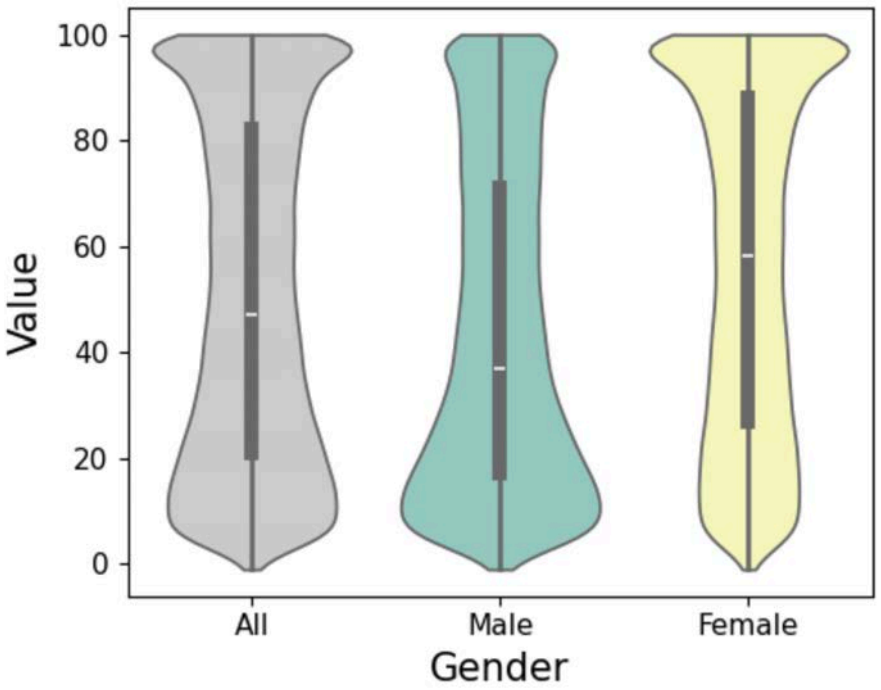


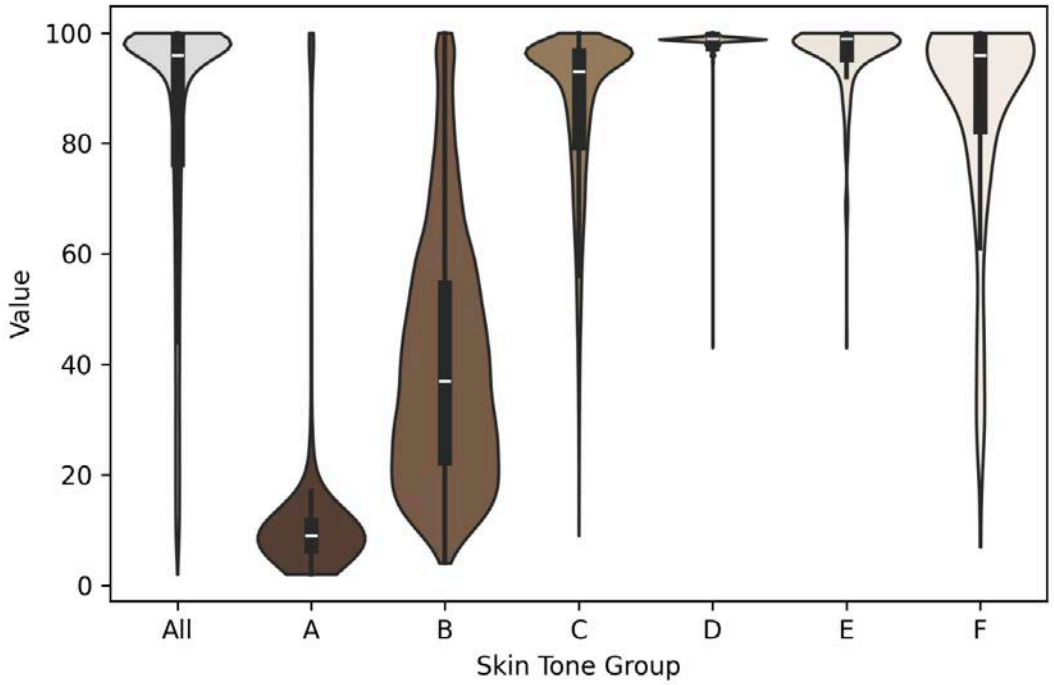
[Utcke2026] S. Utcke et al.: "Demographic Variability of Face Image Quality Measures in Operational Data", in IEEE Access, (2026), https://ieeexplore.ieee.org/document/11411711

Face Image Quality - Demographic Variability

Research tasks

- Investigate variability across demographic groups
  - Distribution of component quality measures (CQM)
    Luminance Mean quality component values:





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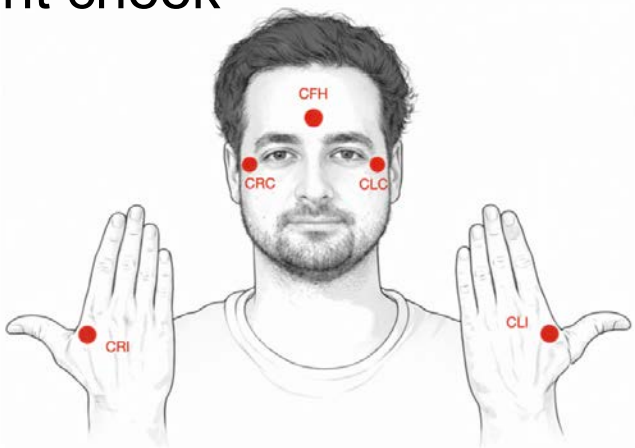
DArmstadt Skin Tone Dataset (DAST)

Ground truth skin tone measurement

- Handheld DSM-4 colorimeter
  - measures a skin area of approximately 50 mm^2 under standardised D65 illumination generated by four light-emitting diodes.
  - Skin color is quantified using diffuse reflectance spectroscopy
- Locations of colorimeter measurements
  - CFH: Colorimeter measure forehead of the face
  - CLC: Colorimeter measure forehead of the left cheek
  - CRC: Colorimeter measure forehead of the right cheek
  - CLI: Colorimeter measure left hand
  - CRI: Colorimeter measure right hand



[Busch2026] C. Busch et al.: A Skin Tone Annotated Face Image Dataset for Studying Demographic Variability", in Proceedings of 14th International Workshop on Biometrics and Forensics (IWBF), (2026)
https://christoph-busch.de/files/Busch-DAST-IWBF-2026.pdf

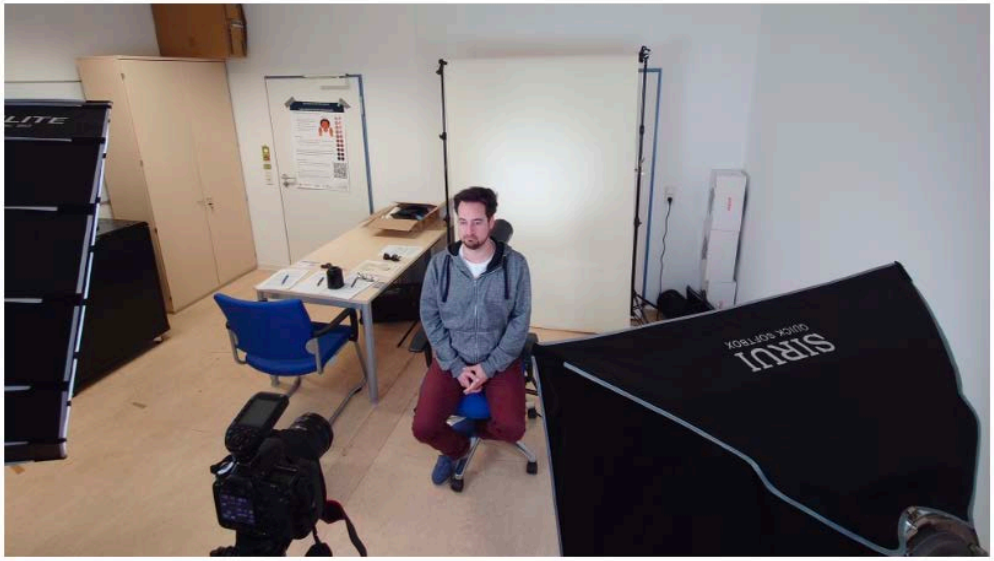
DArmstadt Skin Tone Dataset (DAST)

Ensure homogeneous illumination

- Compliant with ISO/IEC 39794-5:2019, Annex E
- Nanlite SBPR90Q and Sirui Quick Release softboxes

Capture devices

- Canon EOS 50D (3,168×4,752 px) equipped with a Canon EF-S 18–200 mm f/3.5–5.6 IS lens
- Sony ILCE-7M2 (4,000×6,000 px) equipped with a FE 90 mm F2.8 Macro G OSS lens.



DArmstadt Skin Tone Dataset (DAST)

Exposure Levels

- By combining camera and flash settings five distinct exposure levels (ELs) were realised:
  - EL1: strongly underexposed, approximately 25% of the nominal exposure
  - EL2: underexposed, approximately 50% of the nominal exposure
  - EL3: nominal exposure (reference exposure level)
  - EL4: overexposed, approximately 200% of the nominal exposure
  - EL5: strongly overexposed, approximately 400% of the nominal exposure

TABLE I: Settings for face image acquisition.

EL	Flash settings	Camera settings
EL1	small SB 1/8 +0.3 large SB 1/8 BG 1/64	SS 1/100 iso 100 F16
EL2	small SB 1/8 +0.3 large SB 1/8 BG 1/64	SS 1/100 iso 100 F22
EL3	small SB 1/8 +0.3 large SB 1/8 BG 1/64	SS 1/100 iso 100 F11
EL4	small SB 1/4 +0.3 large SB 1/4 BG 1/32	SS 1/125 iso 100 F11
EL5	small SB 1/2 +0.3 large SB 1/2 BG 1/16	SS 1/160 iso 100 F11

SB: Softbox, BG: Background, SS: Shutter speed

DArmstadt Skin Tone Dataset (DAST)

Exposure Levels

- Examples of 12 face images per subject in different illumination conditions
  - 2 cameras
  - 5 exposure levels

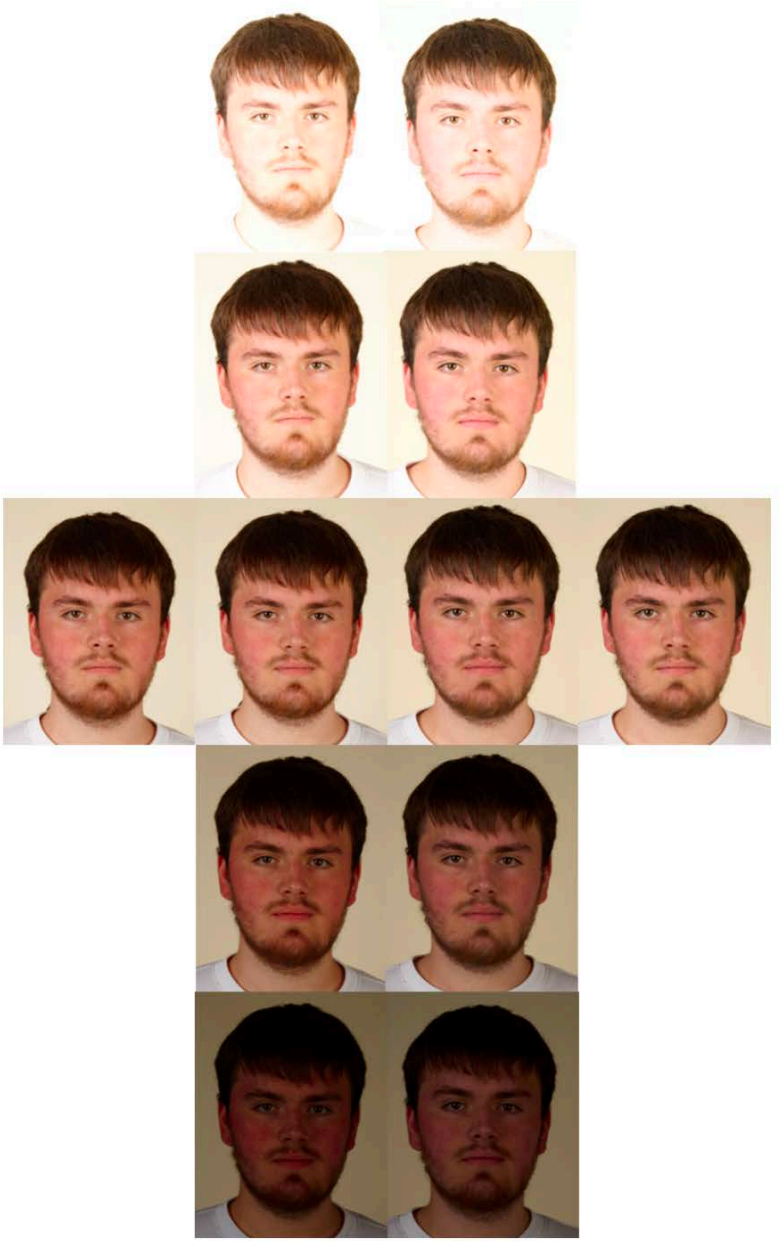


TABLE II: Number of subjects per gender and skin tone class

	CST classes									
Gender	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Male	0	4	8	9	9	8	6	9	8	0
Female	2	6	2	1	1	2	4	1	0	0

TABLE I: Settings for face image acquisition.

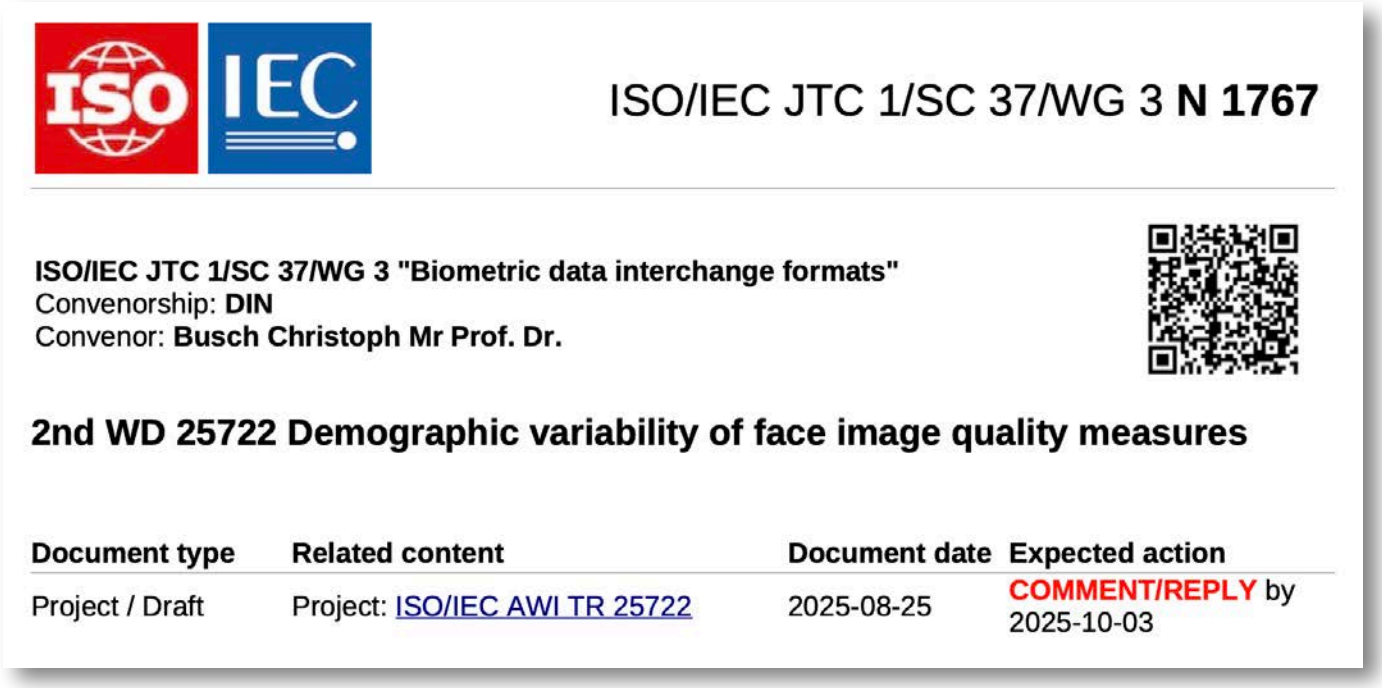
EL	Flash settings	Camera settings
EL1	small SB 1/8 +0.3 large SB 1/8 BG 1/64	SS 1/100 iso 100 F16
EL2	small SB 1/8 +0.3 large SB 1/8 BG 1/64	SS 1/100 iso 100 F22
EL3	small SB 1/8 +0.3 large SB 1/8 BG 1/64	SS 1/100 iso 100 F11
EL4	small SB 1/4 +0.3 large SB 1/4 BG 1/32	SS 1/125 iso 100 F11
EL5	small SB 1/2 +0.3 large SB 1/2 BG 1/16	SS 1/160 iso 100 F11

SB: Softbox, BG: Background, SS: Shutter speed

Face Image Quality - Demographic Variability

Open tasks to investigate DV on operational data

- Distribution of UQS and CQM
- ISO/IEC WD3 TR 25722
  - https://www.iso.org/standard/91308.html
  - https://www.iso.org/committee/313770.html?t=pbkdp2EjRvj8aKJD_DJuyD-UVGVhaafFTG1SHYW1UKrmbchG6jLf6jqoqARosEWf&view=documents#section-isodocuments-top



ISO/IEC JTC 1/SC 37/WG 3 **N 1767**

ISO/IEC JTC 1/SC 37/WG 3 "Biometric data interchange formats"
Convenorship: **DIN**
Convenor: **Busch Christoph Mr Prof. Dr.**

2nd WD 25722 Demographic variability of face image quality measures

Document type	Related content	Document date	Expected action
Project / Draft	Project: ISO/IEC AWI TR 25722	2025-08-25	COMMENT/REPLY by 2025-10-03

FRS with 1KB reference Micro-Container

Compact Face Image Encoding

Containers have limited capacity

- Contact less IC Chip
  - ICAO 9303 passports
    - ISO/IEC14443
  - Target size: 32 Kbyte
- 2D Barcode
  - Temporary travel document
  - Temporary residence permit
    - ISO/IEC 18004:2024 QR code
    - ISO/IEC 16022:2024 Data Matrix
    - ISO/IEC 24778:2024 Aztec code
    - ISO/IEC 15438:2015 PDF417
    - ISO/IEC 16023:2000 Maxicode
  - Target size: 1Kbyte

Temporary eMRTD
Surname: Busch
Givename Christoph
Nationality: German
DoB: yyyymmdd
PoB: Frankfurt
DoE: yyyymmdd

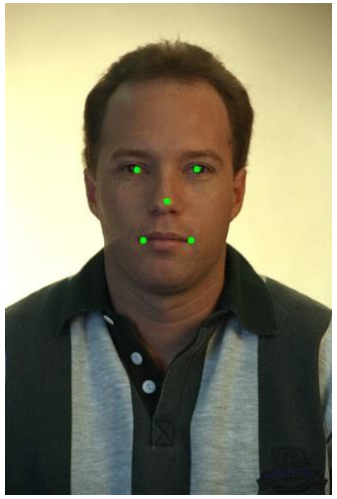
Compact Face Image Encoding

(Pre-) processing

- Face detection, landmarks, cropping and blurring

Original - RGB

Detect landmarks



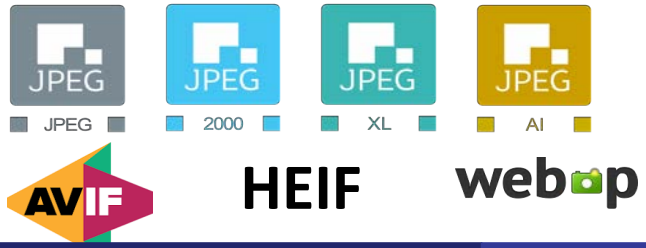
Crop and change to 112x113 px

Monochrome

Blur - outside ROI

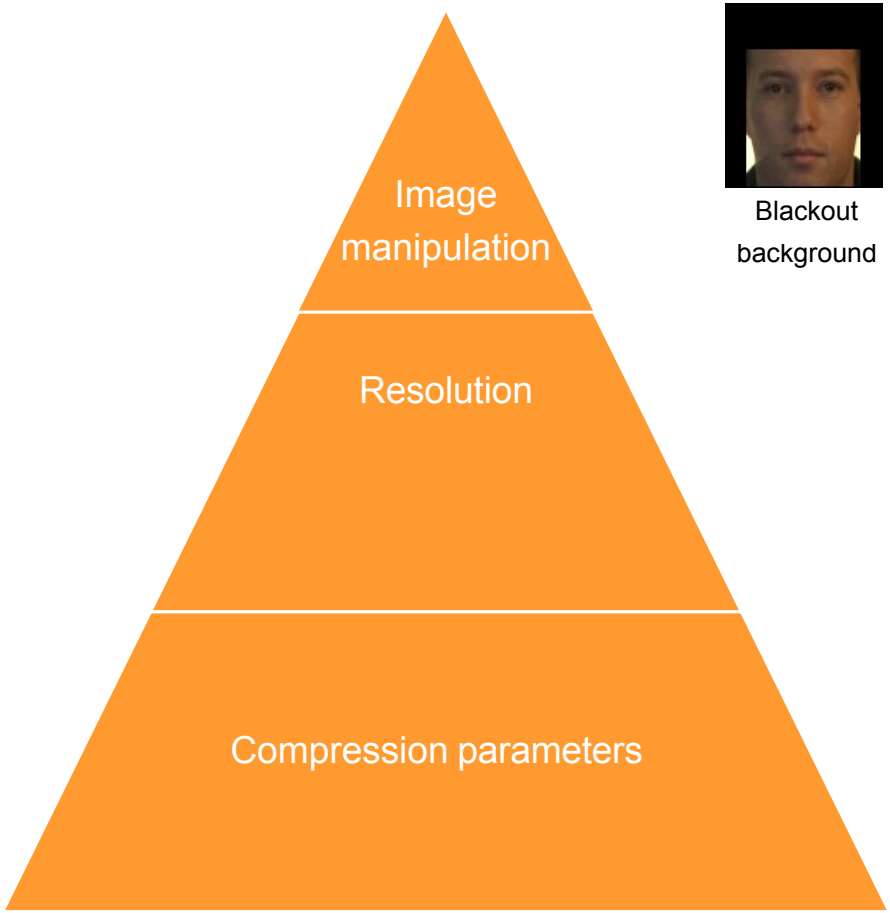
Compress

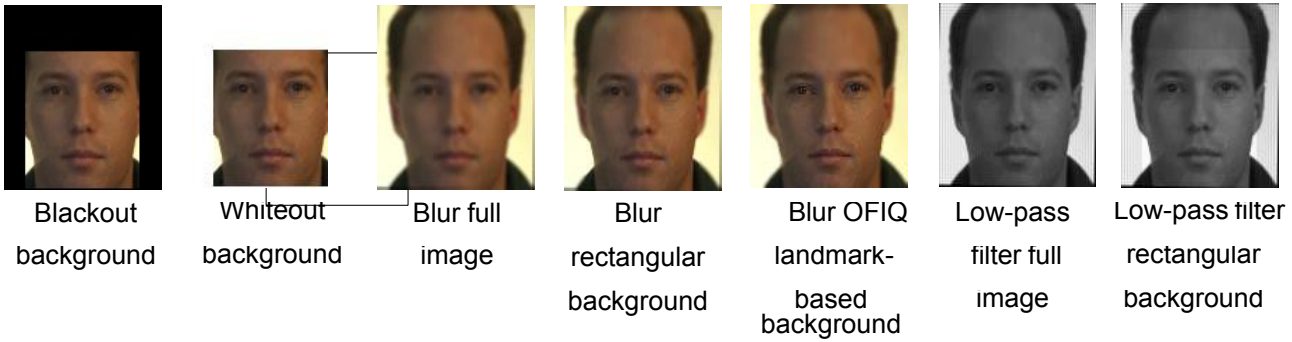
- Compression

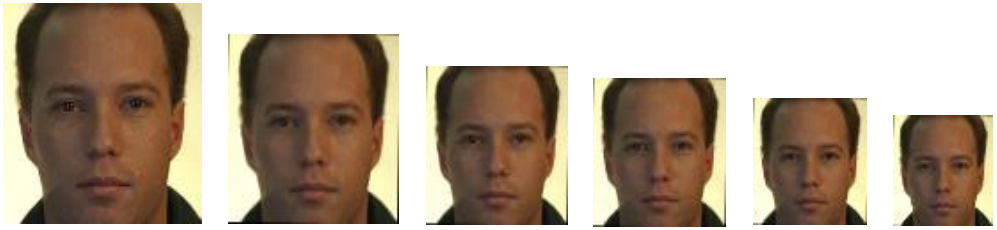


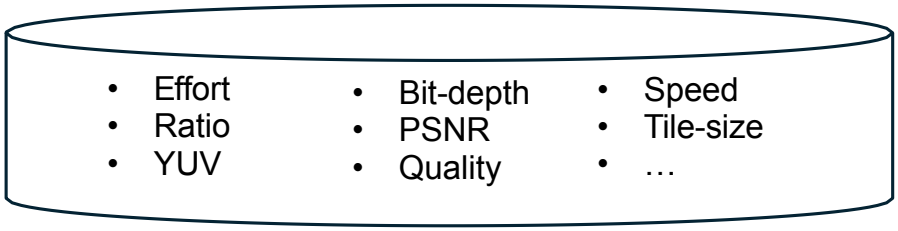
Compact Face Image Encoding

Optimisation





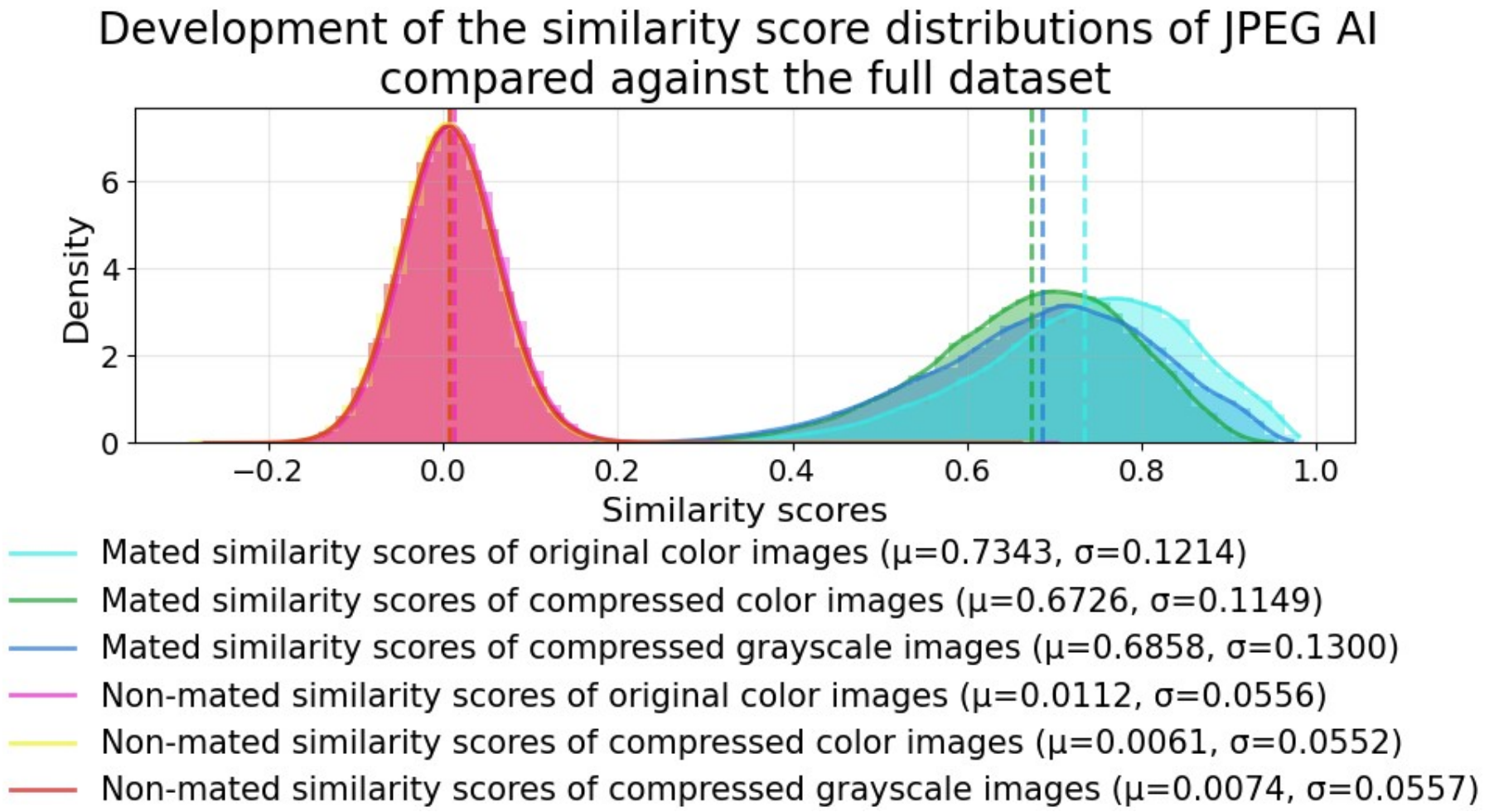




[Busch2026] P. Andreas, T. Schlett, C. Busch: "Optimizing Lossy Image Compression for Face Recognition within 1024 Bytes", in Proceedings of 14th International Workshop on Biometrics and Forensics (IWBF), (2026)
https://christoph-busch.de/files/Andreas-FRwith1kB-IWBF-2026.pdf

Compact Face Image Encoding

Results - score distributions



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Results

Compression algorithm	Settings used	FNMR in % at FMR = 0.01% ↓	False non-matches in total ↓
No compression (baseline)	Color, resolution = 112	0.0100	4
AVIF	YUV format=420, speed=1, color, resolution = 56, rectangle blur	0.0151	6
WebP	Method = 6, SNS = 40, color, resolution = 64, rectangle blur	0.0176	7
JPEG AI	Color, resolution = 180, OFIQ blur	0.0201	8
JPEG XL	Quality, effort = 10, color, resolution = 64, rectangle blur	0.0251	10
JPEG 2000	Ratio, number of resolutions = 3, color, resolution = 56, rectangle blur	0.0251	10
HEIF	Chroma downsampling = average, color, resolution = 96, rectangle blur	0.0276	11
JPEG	Gray, arithmetic, smooth = 50, grayscale, resolution = 96, rectangle blur	0.0878	35

Compact Face Image Encoding

Impact of Lossy Image Compression

- Results with JPEG and JPEG AI


original


AVIF


WebP


JPEG AI

Conclusion

Summary

- Face image quality assessment is accurately possible with open source algorithms
  - OFIQ provides explainable feedback to the user on why a face image is of insufficient quality
- We need to investigate demographic variability of all biometric algorithms
- Face recognition with 1KB reference samples is a new challenge for research

[B2024] C. Busch: "Challenges for Automated Face Recognition Systems", in Nature Reviews Electrical Engineering, (2024), https://christoph-busch.de/files/Busch-NatureReview-ChallengesFRS-2024.pdf

Questions and Answers?

Take home information:

- Face image quality website:
  https://christoph-busch.de/projects-ofiq.html
- Morphing attack detection website:
  https://christoph-busch.de/projects-mad.html