Fingerprint Image Quality
NFIQ2.0

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Outline

- Fingerprint applications and challenges
- Problem statement and requirements
- NFIQ2.0 framework and development
- Identifying candidate features
- NIFQ2.0 Light
- Summary and outlook
Official fingerprint applications

- Official documents with fingerprints
  - European ePassports
  - European Residence Permits
  - Identity Cards (partially)
- European Visa Information System (VIS)
  - Tenprints from all Schengen (short-time) Visa applicants
    - Data stored for 5 years
  - Biometric verification at Schengen border checks has started
- Criminal AFIS
- Future programs might also use fingerprints
  - EU Smart Borders Package (Entry-Exit-System, RTP)
Challenges for operators

- **Technical aspects**
  - Heterogenous environments
  - Different hardware and software vendors and versions
  - Interoperability issues

- **System design**
  - At enrolment stage, typically the biometric verification or identification system vendor is unknown
  - Large scale identification scenarios (AFIS) have high quality requirements
    - 100 million records or more!
Challenges in fingerprint biometrics deployment

- **Timing considerations**
  - Timing constraints are the biggest driver in the design of an enrolment and verification process
  - In many cases, quality correlates directly with time
    - Not only technical, but also organizational (e.g. regarding user guidance)
  - Time is money!
    - Officers are expensive
    - Space is expensive
- **Which quality is required by the system?**
  - How much time (on average) do I need to reach the desired level?
  - Not: How do I achieve maximal quality?
Standardization - then


- Definitions

  - quality: "the degree to which a biometric sample fulfils specified requirements for a targeted application"

  - quality score: "a quantitative expression of quality"

  - utility: "the observed performance of a biometric sample or set of samples in one or more biometric systems"

- Quality score from 0 to 100

<table>
<thead>
<tr>
<th>description</th>
<th>size</th>
<th>valid values</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Quality Blocks</td>
<td>1 byte</td>
<td>[0,255]</td>
<td>This field is followed by the number of 5-byte Quality Blocks reflected by its value</td>
</tr>
<tr>
<td>Quality Score</td>
<td>1 byte</td>
<td>[0,100]</td>
<td>0: lowest 100: highest 255: failed attempt to assign a quality score. In this case, no Quality Blocks are present.</td>
</tr>
<tr>
<td>Quality Algorithm Vendor ID</td>
<td>2 bytes</td>
<td>[1,65535]</td>
<td>Quality Algorithm Vendor ID shall be registered with IBIA as a CBEFF biometric organization. Refer to CBEFF vendor ID registry procedures in ISO/IEC 19785-2.</td>
</tr>
<tr>
<td>Quality Algorithm ID</td>
<td>2 bytes</td>
<td>[1,65535]</td>
<td>Quality Algorithm ID may be optionally registered with IBIA as a CBEFF Product Code. Refer to CBEFF product registry.</td>
</tr>
</tbody>
</table>
Standardization - now

- Based on ISO/IEC 29794-1:201X "Information technology - Biometrics sample quality Part 1: Framework"

- Definitions
  - Same as before, but allows for a vector of quality components

- Goal: Actionable quality

- Each element of quality vector has a score from 0 to 100.
Motivation

- There’s no common understanding of a term like *fingerprint of sufficient quality*
  - Sufficient for which application?
  - Quality requirements differ a lot for different applications (e.g. between one-to-one and one-to-many)
  - Quality is not sufficiently well-defined in the standard
- There’s no common language to establish an interoperable definition of *fingerprint of sufficient quality* for a specific application scenario
  - When developing an application scenario, define a common understanding of the required image quality – at the very beginning!
  - A baseline tool (as common language) is needed for doing this
Joint effort towards NFIQ2.0
NFIQ history / milestones

- 2004: Release of NFIQ-1 by NIST
  - Open source, accepted by the community
  - Only five different values as output (1 – 5)
- March 2010: 1st workshop at IBPC 2010
  - Wish list on NFIQ2.0
    - Open source, generalization, interoperability
    - NFIQ2.0 should follow a similar technical approach – but better, bigger, faster, etc.
- March 2012: 2nd workshop at IBPC 2012
  - Presentation of concepts and first components
- Sept. 2013: Biometric Consortium Conference (BCC 2013)
  - Presentation of the 1st NFIQ2.0 prototype
NFIQ2.0 design considerations

- Modular approach for NFIQ2.0 development is desired
  - to be flexible regarding the implementation
  - to have a common basis of functionality needed for NFIQ2.0 development which might then be extended by exchange of certain modules
  - because project team is distributed and located all over the world
  - because only certain project partners have access to certain fingerprint databases
  - because work can be shared and re-used by others
  - to simplify the development process
NFIQ2.0 development process

- (1) Public call for participation (9 comparison score providers)
  - Feature implementation + evaluations (100+ features)

- (2) Feature implementation + evaluations (100+ features)
  - Machine learning

- (3) Training + Test set construction
- (4) Machine learning
**NFIQ2.0 framework**

![Diagram of NFIQ2.0 framework]

- **Image Format Converter**
  - Input/Output Interface
  - Quality Feature Extraction Module
  - Utility Estimation Module
  - Machine Learning Module

- **Framework**
  - Input/Output Module
  - Quality Feature Extraction Interface
  - Utility Estimation Interface
  - Machine Learning Interface

- **NFIQ 2.0 Development Tools**
  - extractQualityFeatures()
  - calculateUtility()
  - startTraining()
  - ...

- **NFIQ 2.0 light**
  - checkQuality()

- **Database**
  - Fingerprint images
  - Quality features
  - Comparison scores
  - Utility values

- **Filesystem**
  - Feature extraction

- **Quality Feature**
  - Feature extraction

- **Utility**
  - Utility computation
  - Fusion & binning

- **MLP**
  - Prediction
  - Training
NFIQ2.0 features

- **Image/signal processing**
  - Local clarity score
  - Ridge valley uniformity
  - Orientation certainty level
  - Orientation flow
  - Frequency domain analysis
  - Radial power spectrum
  - Gabor filters (several variants)

- **Minutiae based**
  - FingerjetFx
    - Open source implementation from digitalPersona
    - Digitalpersona.com/fingerjetfx
  - Total count of minutia
  - Count of minutia in region of interest
    - Various selection of ROI

**Requirements**
- Must be based on publicly available algorithms
- Standardized interface (inputs and outputs)
Machine learning

- **Two class prediction**
  - High vs. low performers
    - **Class 1:** High performers are images that result in high genuine scores
      - \( > \text{CDF}^{-1}(0.95) \)
    - **Class 0:** Low performers are images that result in false reject
      - Threshold at FMR=0.0001
    - Quality score is the probability that a given image belongs to class 1.
  - Map quality score to recognition rate

- **Random Forest**
  - Ensemble classifier using stochastic process
    - Use vote to determine class memberships
  - Provides class probability in predictions
    - Analysis of features importance and their ranking
  - **Training**
    - About 5000 samples in each of the low and high performers classes
    - 1000 trees in forest
NFIQ2.0 prototype

- Test result :: Boxplot of the output of random forest per quantized comparison score bin for test set
NFIQ2.0 prototype features

- Preliminary feature list
  - Size of fingerprint
  - Ridge valley uniformity
  - Orientation certainty
  - Orientation flow maps
  - Gabor features
  - Minutiae count and quality
  - Simple contrast features
  - Radial power spectrum
NFIQ2.0 prototype performance

NFIQ2.0 Light

- **Motivation**
  - Computation complexity of feature extraction is high
  - Therefore, feature computation not feasible in mobile devices/sensors

- **Suggested solution**
  - Pre-compute a lookup table to speed up the computation

- **Two stage process**
  - Clustering using Self-Organizing Map
  - Prediction using Random Forest
Self Organizing Maps (SOM) for NFIQ2.0 Light


Images divided into blocks

SOM code book
NFIQ2.0 Light process flow


Divide fingerprint image into blocks and look up nearest cluster to get a label

Finger image is transformed into cluster histogram

Quality Score

Random Forest
NFIQ2.0 Light prototype performance
Dissemination as International Standard

- Results from development will be included in ISO/IEC 29794-4:201x "Information technology – Biometrics sample quality Part 4: Finger image data"

- Quality feature classes
  - Global features
  - Local features (blockwise)

- Expected return of research investment
  - Revision of ISO/IEC 29794-4:201x
    - Currently at 2nd working draft
  - Upgrade from Technical Report (TR) to an International Standard (IS)

- NFIQ2.0 complementing the standard as reference implementation
State of play and expectations for the future

- NFIQ2.0 prototype has been presented at the Biometric Consortium Conference (BCC) in September 2013
- Validation of the prototype is currently ongoing
  - Feature selection and validation on large databases

- NFIQ2.0 is expected to be used
  - as baseline tool for defining “fingerprint of sufficient quality”
  - by all major fingerprint-based biometrics systems
  - as calibration base for vendor QA tools
    - Vendor QA tools will not disappear, but – at least – for large scale applications must be comparable (statistically, not on a by-image-basis) to NFIQ2.0

- NFIQ2.0 Light is expected to be implemented in embedded systems and mobile devices (e.g. auto-capture loop of fingerprint sensors)
Thank you!

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  - http://www.bsi.bund.de
- NFIQ2.0: http://www.nist.gov/itl/iad/ig/development_nfiq_2.cfm