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Information technology — Biometric sample quality —

Part 4: Finger image data

Technologies de l'information — Qualité d'échantillon biométrique —

Partie 4: Données d'image de doigt

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Foreword

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 37, *Biometrics*.

This second edition cancels and replaces the first edition (ISO/IEC 29794-4:2017), which has been technically revised.

The main changes are as follows:

— algorithms for normalization of finger image quality components have been added, along with new quality algorithm identifiers for the unique identification of the quality measures defined in this document;

— Annex A has been technically revised to reflect a new conformance test set.

A list of all parts in the ISO/IEC 29794 series can be found on the ISO and IEC websites.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees.

Introduction

This document specifies finger image quality measures. A reference implementation of the normative measures — NFIQ 2 — is available at Reference [16], which is described in more detail by the developers in Reference [1].

The quality of finger image data is determined by the degree to which the finger image data fulfils specified requirements for the targeted application. Information on quality is therefore useful in many applications. ISO/IEC 19784-1 allocates a quality field and specifies the allowable range for the scores, with a recommendation that the score be divided into four categories with a qualitative interpretation for each category. Finger image quality fields are provided in the finger image data interchange formats standardized in ISO/IEC 19794-4 and ISO/IEC 39794-4. Finger feature data interchange formats standardized in ISO/IEC 19794-2, ISO/IEC 19794-3, ISO/IEC 19794-8 and ISO/IEC 39794-2 provide finger image quality fields for the source image. To facilitate the interpretation and interchange of finger image quality scores, this document specifies how to calculate the finger image quality score of plain finger images with a spatial sampling rate of 196,85 px/cm and a bit depth of 8 bit for the greyscale pixel intensity values scanned from inked fingerprint cards or captured using optical area sensors based on frustrated total internal reflection.

Information technology — Biometric sample quality —

Part 4:
Finger image data

1 Scope

This document establishes:

— terms and definitions for quantifying finger image quality;

— methods used to quantify the quality of finger images; and

— standardized encoding of finger image quality;

for finger images at 196,85 px/cm spatial sampling rate and a bit depth of 8 bit for the greyscale pixel intensity values scanned or captured using optical area sensors in direct contact with friction ridges.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 2382-37, *Information technology — Vocabulary — Part 37: Biometrics*

ISO/IEC 39794-1, *Information technology — Extensible biometric data interchange formats — Part 1: Framework*

ISO/IEC 29794-1, *Information technology — Biometric sample quality — Part 1: Framework*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 2382-37, ISO/IEC 29794-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
foreground region
set of all pixels of a finger image that form valid finger image patterns

Note 1 to entry: The most evident structural characteristic of a valid finger image is a pattern of interleaved ridges and valleys.

3.2
local region
block of $m \times n$ pixels of the foreground region, where m and n are smaller than or equal to the width and the height of the foreground region respectively

3.3
finger image quality assessment algorithm
algorithm to calculate a quality measure

Note 1 to entry: "Quality assessment algorithm" and "quality algorithm" are synonyms.

3.4
trim
removal of pixels from the top, left, bottom and right sides of a finger image that do not comprise the foreground region

Note 1 to entry: The steps for trimming an image to form the foreground region are defined in 6.1.5.2.

4 Abbreviated terms

CBEFF	Common Biometric Exchange File Format
DFT	discrete Fourier transform
DT	determine threshold
FDA	frequency domain analysis
FJFX	FingerJet Fingerprint Feature Extractor, Open Source Edition
LCL	local clarity
NFIQ	NIST Fingerprint Image Quality
OCL	orientation certainty level
OFL	orientation flow
QSND	quality score normalisation dataset
RVU	ridge valley uniformity
TIR	total internal reflection

5 Conformance

A finger image quality assessment algorithm conforms to this document if it conforms to the normative requirements of Clause 6.

A finger image quality block shall conform to this document if its structure and data values conform to the formatting requirements of Clause 7 (finger image quality block) and if its quality values are computed using the methods specified in 6.2 and 6.4.

A finger image quality assessment implementation conformant to this document may use the biometric organization identifier of ISO/IEC JTC 1/SC 37, which is 257 (101_{Hex}), if it has been tested following the conformance testing methodology in Clause A.2.

Conformance to normative requirements of Clause 7 is achieved by Level 1 and Level 2 conformance as specified in ISO/IEC 39794-1:2019, Annex C. Conformance to normative requirements of 6.2 and 6.4 is achieved by Level 3 conformance as specified in ISO/IEC 39794-1:2019, Annex C.

The conformance test assertion in Annex A shall apply.

6 Finger image quality measures

6.1 Overview

6.1.1 General

This clause establishes measures for predicting the utility of a finger image. Image quality measures from a single image are useful to ensure the acquired image is suitable for recognition.

A complete finger image quality analysis shall examine both the local and global structures of the finger image. Fingerprint local structure constitutes the main texture-like pattern of ridges and valleys within a local region while valid global structure puts the ridges and valleys into a smooth flow for the entire fingerprint. The quality of a finger image is determined by both its local and global structures. This clause describes the features and characteristics of finger images at both local and global structures that are to be used as quality components for quantifying finger image quality.

For applying the algorithms as described in 6.2 and 6.3, the finger image shall have a spatial sampling rate of 196,85 pixels per centimetre (500 pixels per inch), a bit depth of 8 bit for the greyscale pixel intensity values, with friction ridges represented by greyscale pixel intensity values lower than those for valleys. The algorithms were developed using images of finger friction ridges in contact with an electronic capture device and inked fingerprints digitized with an electronic scanner. The imaging devices and scanners are considered free from geometric distortion and exhibit greyscale linearity and uniformity.

ISO/IEC 29794-1 requires that quality components be mapped to an integer value between 0 and 100, inclusive.

6.1.2 Methods for mapping to the desired value range

6.1.2.1 Sigmoid function

The mapping of values between 0 and 1 inclusive is accomplished for several quality components with the sigmoid function as shown in Formula (1):

$$\text{sigmoid}(x, x_0, w) = \left(1 + \exp\left(\frac{x_0 - x}{w}\right)\right)^{-1} \tag{1}$$

where

x is a native quality measure value;

x_0 is the inflection point at which the function has the value 0,5;

w is a scaling parameter determining the width of the region in which the function transitions from ε to $1-\varepsilon$;

ε is an infinitesimally small positive quantity.

The values computed from the sigmoid function will be mapped to the target value ranges (0 to 100) in subsequent clauses.

6.1.2.2 Known ranges

When the range of values for a given quality measure is known (e.g. from 1 to 250, inclusive), the known range function is used, as shown in Formula (2):

$$\left\lfloor \frac{x - \min(x)}{\max(x) - \min(x) + \varepsilon} 101 \right\rfloor \tag{2}$$

where

x is a native quality measure value;

$\lfloor x \rfloor$ is the floor function giving the greatest integer $\leq x$

ε is an infinitesimally small positive quantity.

6.1.3 Constituent of local quality measures

A finger image is partitioned into local regions such that each local region contains sufficient ridge-valley information, preferably having at least two clear ridges, while not overly constraining high curvature ridges. For images with a spatial sampling rate of 196,85 pixels per centimetre (500 pixels per inch), the ridge separation usually varies between 8 pixels to 12 pixels.[2] A ridge separation comprises a ridge and a valley. In order to cover two clear ridges, the local region size has to be greater than 24 pixels in both width and height. The size for each local region shall be (32 × 32) pixels, which is sufficient to cover two clear ridges. Instead of Cartesian coordinate, curvilinear coordinate along the ridge can also be used.

NOTE The size of the local region used during computation of $q_{\mathrm{OFL}}^{\sigma}$ (6.2.16.3), q_{OFL}^{μ} (6.2.16.2), $q_{\mathrm{COH}}^{\mathrm{sum}}$ (6.2.14), and $q_{\mathrm{COH}}^{\mathrm{rel}}$ (6.2.15) in the reference implementation NFIQ 2 prior to version 2.3.0 deviates from size specified in this subclause.

6.1.4 Constituent of global quality measures

A global quality measure shall be computed over the whole finger image after trim to assess the utility of the sample for fingerprint recognition.

6.1.5 Image preprocessing

6.1.5.1 Description

A segmentation process follows where each local region is labelled as background or foreground. There are several segmentation approaches, such as using the average magnitude of the pixel-intensity gradient in each local region.[2]

This document does not prescribe segmentation methods, but notes that performing segmentation influences several quality components. Constant or near constant areas of the input image shall be removed according to 6.1.5.2 prior to computing quality using the measures specified in 6.2 and 6.3.

See Annex C for the area consideration.

6.1.5.2 Removal of near constant rows and columns in image

Prior to computing quality components, fingerprint images shall be trimmed to remove near constant rows and columns on the margins. Pixel intensities take values [0, 255] for an 8-bit greyscale image. As a first approximation of the region of interest, image columns and rows which are near constant white background are removed. Using the algorithm specified below, a fixed threshold, T_{μ}, is set to the greyscale pixel intensity of 250 to obtain the image without near constant areas.

The algorithm is visualized in Figure 1 and specified as follows:

a) For each row R_i in $\hat{\boldsymbol{I}}$, starting from the top:

   1) compute the row arithmetic mean μ_{row};

   2) on the first occurrence where $\mu_{\mathrm{row}} \leq T_{\mu}$ set $\mathrm{top} = R_i$;

3) on the last occurrence where $\mu_{row} \leq T_{\mu}$ set $\text{bottom} = R_i$.

b) For each column C_i in $\hat{\boldsymbol{I}}$, starting from the left:

1) compute the column arithmetic mean μ_{col};

2) on the first occurrence where $\mu_{col} \leq T_{\mu}$ set $\text{left} = C_i$;

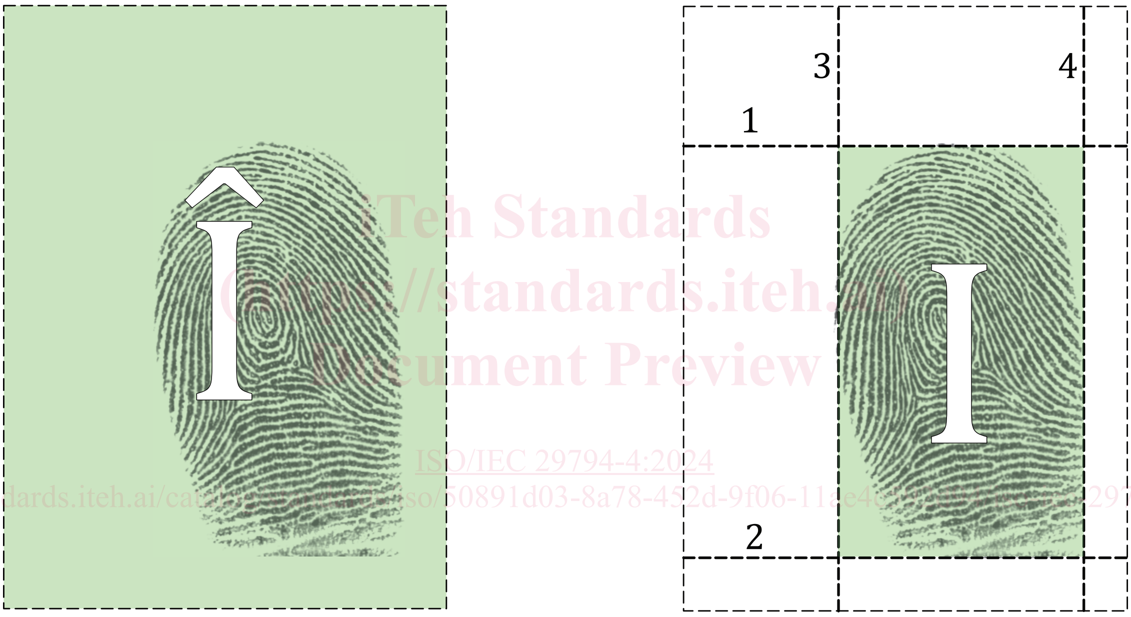
3) on the last occurrence where $\mu_{col} \leq T_{\mu}$ set $\text{right} = C_i$.

c) extract the trimmed region of interest, $\boldsymbol{I}$, as the pixels of $\hat{\boldsymbol{I}}$ encompassed between and including the rows top (a2) and bottom (a3) and the columns left (b2) and right (b3).

where

$\hat{\boldsymbol{I}}$ is the matrix of grey levels corresponding to the pixels of an image;

$\boldsymbol{I}$ is the matrix of grey levels corresponding to the pixels of an image after trim.



a) Image prior to trimming near constant rows and columns on the margins

b) Results of following the steps in 6.1.5.2

Key

1 top

2 bottom

3 left

4 right

NOTE 1 In Figure 1 a), the area overlayed in green is a visualisation of $\hat{\boldsymbol{I}}$.

NOTE 2 In Figure 1 b), the area overlayed in green is a visualisation of $\boldsymbol{I}$.

NOTE 3 Each subfigure within Figure 1 contains a dashed black border.

Figure 1 — Example of removing near constant white rows and columns from an image

6.1.5.3 Foreground segmentation based on local standard deviation

For quality components that require a foreground mask to indicate regions containing the fingerprint, an algorithm using local standard deviation is adopted.

The algorithm is specified as follows:

a) Normalize $\boldsymbol{I}$ to zero mean and unit standard deviation to produce $\boldsymbol{I}'$.

b) For each local region $\boldsymbol{V}$ in $\boldsymbol{I}'$:

   1) compute the standard deviation of $\boldsymbol{V}$ as σ_{V};

   2) mark the corresponding local region in $\boldsymbol{I}_{\mathrm{mask}}$ as foreground if $\sigma_{\mathrm{V}} > 0{,}1$.

6.1.5.4 Computing the dominant ridge flow orientation for a local region from pixel-intensity gradients

The dominant ridge flow orientation is determined by computing the pixel-intensity gradient information and then determining the orientation of the principal variation axis.

The numerical gradient of the local region is determined using finite central difference for all interior pixels in *x*-direction and *y*-direction, as shown in Formulae (3) and (4):

$$f_{\mathrm{x}} = \frac{\boldsymbol{I}(x+1,y) - \boldsymbol{I}(x-1,y)}{2} \tag{3}$$

$$f_{\mathrm{y}} = \frac{\boldsymbol{I}(x,y+1) - \boldsymbol{I}(x,y-1)}{2} \tag{4}$$

With f_{x} and f_{y}, the dominant ridge flow orientation, $\mathrm{angle}(\boldsymbol{V})$, is determined analytically using the sine and cosine doubled angle determined from the arithmetic means of the pixel-intensity gradient covariances, as shown in Formulae (5) to (12):

$$a = \overline{f_{\mathrm{x}}^2} \tag{5}$$

$$b = \overline{f_{\mathrm{y}}^2} \tag{6}$$

$$c = \overline{f_{\mathrm{x}} f_{\mathrm{y}}} \tag{7}$$

$$C = \begin{bmatrix} a & c \\ c & b \end{bmatrix} \tag{8}$$

$$d = \sqrt{c^2 + (a-b)^2} \tag{9}$$

$$\sin(\theta) = \frac{c}{d} \tag{10}$$

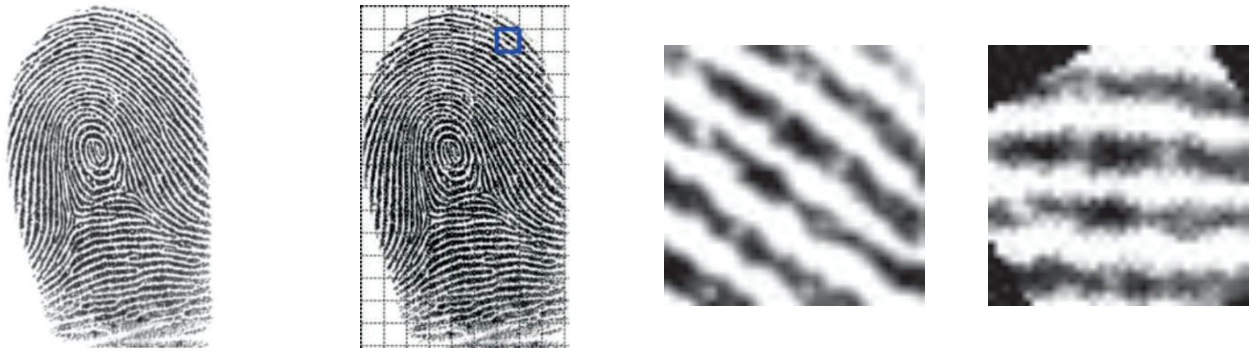
$$\cos(\theta) = \frac{a-b}{d} \tag{11}$$

$$\mathrm{angle}(\boldsymbol{V}) = \frac{1}{2}\arctan\left(\frac{\sin(\theta)}{\cos(\theta)}\right) \tag{12}$$

NOTE In Formulae (5), (6) and (7), the use of the overbar indicates the mean of the value.

6.1.6 Image examples

For algorithms operating in a block-wise manner the trimmed input image is subdivided into local regions according to an overlay grid. This is demonstrated in Figure 2 b), in which the local region ***V*** (6,1) is used as an example in local processing and is marked up using a bold blue line. Figure 2 c) shows an enlarged view of ***V*** (6,1) and Figure 2 d) shows ***V*** (6,1) rotated according to its dominant ridge orientation computed using Formula (12).



a) Input finger image **b) Division into local regions** **c) Enlarged view of *V* (6,1)** **d) *V* (6,1) rotated according to its dominant ridge orientation as determined using Formula (12)**

Figure 2 — Example of computing the dominant ridge flow orientation for a local region

6.2 Normative contributive quality components

6.2.1 General

Subclause 6.2 specifies algorithms for computing finger image quality components that contribute to the ISO/IEC 29794-4 quality feature vector and to the computation of the unified quality score.

6.2.2 Orientation certainty level

6.2.2.1 Description

The orientation certainty level (OCL)[3] of a local region is a measure of the consistency of the orientations of the ridges and valleys contained within this local region. The feature computes local quality and operates in a block-wise manner.

The finger image within a (32 × 32) pixels local region [as shown in Figure 2 c)] generally consists of dark ridge lines separated by white valley lines along the same orientation. The consistent ridge orientation and the appropriate ridge and valley structure are distinguishable local characteristics of the fingerprint local region.

The pixel-intensity gradient (*dx*, *dy*) at a pixel describes the direction of the maximum pixel-intensity change and its strength. By performing principal component analysis on the pixel-intensity gradients in a local region, an orthogonal basis for the local region can be formed by finding its eigenvalues and eigenvectors. The resultant first principal component contains the largest variance contributed by the maximum total gradient change in the direction orthogonal to ridge orientation. The direction is given by the first eigenvector and the value of the variance corresponds to the first eigenvalue, λ_{max}. On the other hand, the resultant second principal component has the minimum change of gradient in the direction of ridge flow which corresponds to the second eigenvalue, λ_{min}. The ratio between the two eigenvalues thus gives an indication of the strength of the energy concentrated along the dominant direction with two vectors pointing to the normal and tangential direction of the average ridge flow respectively.

6.2.2.2 Computing the eigenvalues and local orientation certainty

From the covariance matrix $\boldsymbol{C}$ [Formula (8)] the eigenvalues $\lambda_{\min}$ and $\lambda_{\max}$ are computed as shown in Formulae (13) and (14):

$$\lambda_{\min} = \frac{a+b-\sqrt{(a-b)^2+4c^2}}{2} \quad (13)$$

$$\lambda_{\max} = \frac{a+b+\sqrt{(a-b)^2+4c^2}}{2} \quad (14)$$

This yields the local orientation certainty level shown in Formula (15):

$$q_{\mathrm{OCL}}^{\mathrm{local}} = \begin{cases} 1-\dfrac{\lambda_{\min}}{\lambda_{\max}}, & \text{if } \lambda_{\max}>0 \\ 0, & \text{otherwise.} \end{cases} \quad (15)$$

which is a ratio in the interval [0,1] where 1 is highest certainty level and 0 is lowest.

NOTE The orientation certainty level fails to predict recognition performance when some marks or residue exist in the samples that have strong orientation strength, such as those exhibited by latent prints left by the previous user of a capture device.

6.2.2.3 OCL algorithm

For each local region $\boldsymbol{V}$ in $\boldsymbol{I}$:

a) compute the pixel-intensity gradient of $\boldsymbol{V}$ with the centred differences method [Formulae (3), (4)];

b) compute the covariance matrix $\boldsymbol{C}$ [Formula (8)];

c) compute the eigenvalues of $\boldsymbol{C}$ to obtain $q_{\mathrm{OCL}}^{\mathrm{local}}$ [Formulae (13), (14), (15)].

Figure 3 visualizes the processing steps.

a) Current local region with the ratio between eigenvalues marked as ellipse

b) Original, untrimmed image and its $q_{\mathrm{OCL}}^{\mathrm{local}}$ values, mapped to values 0-255

Figure 3 — Processing steps of orientation certainty level quality algorithm