INTERNATIONAL STANDARD

ISO/IEC 29794-4

First edition
2017-09

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

Reference number
ISO/IEC 29794-4:2017(E)

Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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

This first edition cancels and replaces ISO/IEC/TR 29794-4:2010, which has been technically revised to become an International Standard.

A list of all parts in the ISO 29794 series can be found on the ISO website.

Introduction

This document specifies finger image quality metrics. A reference implementation of the normative metrics is available at https://github.com/usnistgov/NFIQ2.

The quality of finger image data is defined to be the degree to which the finger image data fulfils specified requirements for the targeted application. Thus, the quality information is 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. Image quality fields are also provided in the fingerprint data interchange formats standardized in ISO/IEC 19794-2, ISO/IEC 19794-3, ISO/IEC 19794-4, and ISO/IEC 19794-8. This document defines a standard way to calculate the finger image quality score that facilitates the interpretation and interchange of the finger image quality scores.

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 scanned or captured using optical sensors with capture dimension (width, height) of at least 1,27 cm × 1,651 cm.

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 19794-1:2011, *Information technology — Biometric data interchange formats — Part 1: Framework*

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

3 Terms, definitions, symbols and abbreviated terms

3.1 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 terminological databases for use in standardization at the following addresses:

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

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

3.1.1
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.

3.1.2
local region
block of $m \times n$ pixels of the foreground of a finger image, where m and n are smaller than or equal to the width and the height of the finger image

3.1.3
finger image quality assessment algorithm
algorithm that reports a quality score for a given finger image

3.1.4
metric
quantification of a covariate using a prescribed method

3.1.5
covariate
variable or parameter that either directly, or when interacting with other covariates, affects fingerprint recognition accuracy

3.2 Symbols and abbreviated terms

DFT Discrete Fourier Transform

$\boldsymbol{I}$ matrix of grey-level intensity values corresponding to the pixels of an image

$\boldsymbol{S}$ ridge valley signature of a local region V

$\boldsymbol{V}$ matrix of grey-level intensity values corresponding to the pixels of a local region

4 Conformance

A finger image quality assessment algorithm conforms to this document if it conforms to the normative requirements of Clause 5.

A finger image quality record shall conform to this document if its structure and data values conform to the formatting requirements of Clause 6 (finger image quality data record) and its quality values are computed using the methods specified in 5.2, 5.3 and 5.4.

Conformance to normative requirements of Clause 6 fulfils Level 1 and Level 2 conformance as specified in ISO/IEC 19794-1:2011, Annex A. Conformance to normative requirements of 5.2 and 5.4 is Level 3 conformance as specified in ISO/IEC 19794-1:2011, Annex A.

5 Finger image quality metrics

5.1 Overview

5.1.1 General

Clause 5 establishes metrics for predicting the utility of a finger image (5.2 and 5.3). Image quality metrics 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. Clause 5 describes the features and characteristics of finger images at both local and global structures that are to be used for quantifying finger image quality.

For applying the algorithms as described in 5.2 and 5.3, the finger image shall have a spatial sampling rate of 196,85 pixels per centimetre (500 pixels per inch).

5.1.2 Constituent of local quality metrics

A finger image is partitioned into local regions such that each local region contains sufficient ridge-valley information, preferably having at least 2 clear ridges, while not overly constraining the high curvature ridges. For images with a spatial sampling rate of 196,85 pixel per centimetre (500 pixel per inch), the ridge separation usually varies between 8 pixels to 12 pixels[1]. 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 2 clear ridges. Instead of Cartesian coordinate, curvilinear coordinate along the ridge can also be used.

5.1.3 Constituent of global quality metrics

A global quality metric should be computed over the whole image and assess the utility of fingerprint characteristics in the image.

5.1.4 Image preprocessing

5.1.4.1 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[1].

This document does not prescribe segmentation methods, but notes that performing segmentation influences the computed scores. Constant or near constant areas of the input image shall be removed according to 5.1.4.2 prior to computing quality using the metrics specified in 5.2 and 5.3.

5.1.4.2 Removal of near constant white lines in image

Prior to computing features, fingerprint images are cropped to remove white pixels on the margins. Starting from the outer margins, rows and columns with average pixel intensity above 250 are removed.

Pixel intensities take values [0, 255] for an 8-bit gray scale 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 is set for gray scale pixel intensity of $T_\mu = 250$ to obtain the image without near constant areas.

The algorithm is specified as:

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

   1) Compute the row arithmetic mean μ_{row}

   2) On the first occurrence where $\mu_{\text{row}} \leq T_\mu$ set $idx_t = i$

   3) On the last occurrence where $\mu_{\text{row}} \leq T_\mu$ set $idx_b = i$

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

   1) Compute the column arithmetic mean μ_{col}

   2) On the first occurrence where $\mu_{\text{col}} \leq T_\mu$ set $idx_l = i$

   3) On the last occurrence where $\mu_{\text{col}} \leq T_\mu$ set $idx_r = i$

c) Extract the region of interest as $\hat{\boldsymbol{I}} = \boldsymbol{I}.\text{roi}(idx_l, idx_t, idx_r, idx_b)$

5.1.4.3 Foreground segmentation based on local standard deviation

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

The algorithm is specified as:

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

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

1) Compute the standard deviation of $\boldsymbol{V}$ as $\sigma_{\boldsymbol{V}}$

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

5.1.4.4 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

$$\boldsymbol{f}_x = \frac{\boldsymbol{I}(x+1,y) - \boldsymbol{I}(x-1,y)}{2} \tag{1}$$

$$\boldsymbol{f}_y = \frac{\boldsymbol{I}(x,y+1) - \boldsymbol{I}(x,y-1)}{2} \tag{2}$$

With $\boldsymbol{f}_x$ and $\boldsymbol{f}_y$, the dominant ridge flow orientation, *angle* ($\boldsymbol{V}$), is determined analytically using the sine and cosine doubled angle determined from the arithmetic means of the pixel-intensity gradient covariances.

$$a = \overline{\boldsymbol{f}_x^2} \tag{3}$$

$$b = \overline{\boldsymbol{f}_y^2} \tag{4}$$

$$c = \overline{\boldsymbol{f}_x \boldsymbol{f}_y} \tag{5}$$

$$\boldsymbol{C} = \begin{bmatrix} a & c \\ c & b \end{bmatrix} \tag{6}$$

$$d = \sqrt{c^2 + (a-b)^2} + \epsilon \tag{7}$$

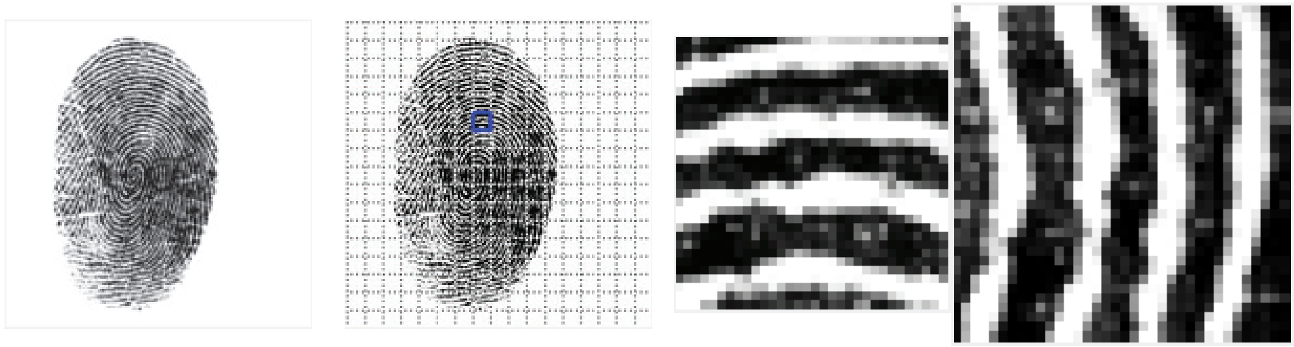
$$\sin\theta = \frac{c}{d} \tag{8}$$

$$\cos\theta = \frac{a-b}{d} \tag{9}$$

$$angle(\boldsymbol{V}) = \frac{1}{2}\tan^{-1}\frac{\sin\theta}{\cos\theta} \tag{10}$$

5.1.5 Image examples

For algorithms operating in a block-wise manner the input image is subdivided into local regions according to the overlay grid shown in Figure 1 b). The local region ***V***(8,5) is used as example in local processing and is marked up using a bold line. Figure 1 c) shows an enlarged view of ***V***(8,5) and Figure 1 d) shows ***V***(8,5) rotated according to its dominant ridge orientation computed using Formula (10).



a) Input finger image **b) division into local regions** **c) enlarged view of *V*(8,5)** **d) *V*(8,5) rotated according to its dominant ridge orientation as determined using Formula (10)**

Figure 1 — Input image used — Examples of the processing of quality

5.2 Normative contributive quality metrics

5.2.1 General

5.2 specifies normative contributive finger image quality assessment algorithms.

5.2.2 Orientation certainty level

5.2.2.1 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 1 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 how strong the energy is concentrated along the dominant direction with two vectors pointing to the normal and tangential direction of the average ridge flow respectively.

5.2.2.2 Computing the eigenvalues and local orientation certainty

From the covariance matrix ***C*** [Formula (6)] the eigenvalues $\lambda_{\min}$ and $\lambda_{\max}$ are computed as

$$\lambda_{\min} = \frac{a+b-\sqrt{(a-b)^2+4c^2}}{2} \tag{11}$$

$$\lambda_{\max} = \frac{a+b+\sqrt{(a-b)^2+4c^2}}{2} \tag{12}$$

which yields a local orientation certainty level

$$\boldsymbol{Q}_{\mathrm{OCL}}^{local} = \begin{cases} 1-\dfrac{\lambda_{\min}}{\lambda_{\max}}, & if \quad \lambda_{\max}>0 \\ 0, & \text{otherwise} \end{cases} \tag{13}$$

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 match-ability when some marks or residual exist in the samples that have strong orientation strength, such as those exhibited by latent prints left by the previous user.

5.2.2.3 OCL algorithm

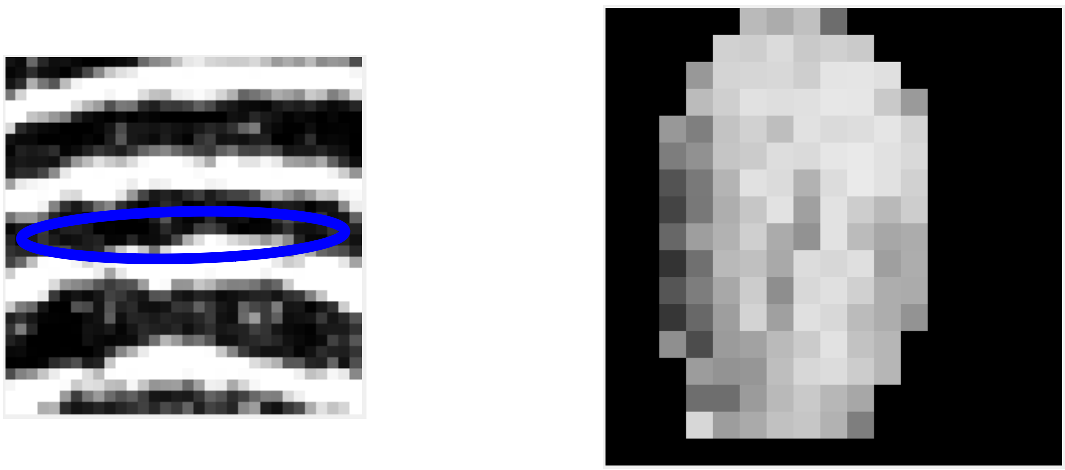
For each local region ***V*** in ***I***:

a) compute the pixel-intensity gradient of ***V*** with centered differences method [Formulae (1), (2)];

b) compute the covariance matrix ***C*** [Formula (6)];

c) compute the eigenvalues of ***C*** to obtain $\boldsymbol{Q}_{\mathrm{OCL}}^{local}$ [Formulae (11), (12), (13)].

Figure 2 visualizes the processing steps.



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

b) Local quality scores $\boldsymbol{Q}_{\mathrm{OCL}}^{local}$ for example fingerprint image

Figure 2 — Processing steps of orientation certainty level quality algorithm

5.2.3 Local clarity score

5.2.3.1 Description

Good quality fingerprints exhibit clear ridge-valley structure. Thus, the local clarity score (LCS) [4], which is the measure of the ridge-valley structure clarity, is a useful indicator of the quality of a fingerprint. The feature computes local quality and operates in a block-wise manner.

To perform ridge-valley structure analysis, the foreground of the finger image is quantised into local regions of size 32 × 32 pixels[3]. Inside each local region, an orientation line, which is perpendicular to the ridge direction, is computed. At the centre of the local region along the ridge direction, a local region of size 32 × 16 pixels shall be extracted and transformed to a vertically aligned local region.

On $\boldsymbol{S}$, the local region average profile, calculated in 5.2.3.4, a linear regression (or least square fitting) is applied to determine the Determine Threshold (DT) which is a line positioned at the centre of the local region $\boldsymbol{V}$, and is used to segment the local region into the ridge or valley region. Regions with grey level intensity lower than DT are classified as ridges. Otherwise, they are classified as valleys.

Since good finger images cannot have ridges that are too close or too far apart, the nominal ridge and valley thickness can be used as a measure of the quality of the finger image captured. Similarly, ridges that are unreasonably thick or thin indicate that the finger image may not be captured properly, such as pressing too hard or too soft, or the image is a residual sample. Thus, the finger image quality can be determined by comparing the ridge and valley thickness to each of their nominal range of values. Any value out of the nominal range may imply a bad quality ridge pattern. To normalize the range of the thickness values, a pre-set maximum thickness is used. The maximum ridge or valley thickness ($W_{\max}$) for a good finger image is estimated at 20 pixels for a 196,85 pixel per centimetre (500 pixel per inch). The pre-set value of 20 pixel for a 196,85 pixel per centimetre (500 pixel per inch) scanner spatial sampling rate is obtained from the median of the typical ridge separation of 8 to 12 pixels[1], and assuming that any ridge separation will not exceed twice of the median value. This will ensure that the pre-set value is indeed the maximum to limit the value of the normalized ridge and valley thickness between 0 and 1. The ridge thickness (W_r) and valley thickness (W_v) are then normalized with respect to the maximum thickness.

With the ridge and valley separated as above, a clarity test can be performed in each segmented rectangular 2-D region.

For local regions with good clarity, the pixel-intensity distribution of ridges and the pixel-intensity distribution of the valleys have a very small overlapping area and thus $\boldsymbol{Q}_{\mathrm{LCS}}^{local}$ is high. The following factors affect the size of the total overlapping area:

a) noise on ridge and valley;

b) water patches on the image due to wet fingers;

c) incorrect orientation angle due to the effect of directional noise;

d) scar across the ridge pattern;

e) highly curved ridges;

f) ridge endings, bifurcations, delta and core points;

g) incipient ridges, sweat pores and dots.

Factors a) to c) are physical noise found in the image. Factors d) to g) are actual physical characteristics of the fingerprint.

5.2.3.2 Computing the ridge valley signature of a local region

Given the local region $\boldsymbol{V}$ the ridge valley signature $\boldsymbol{S}$ is obtained by

$$\boldsymbol{S}(x)=\frac{\sum_{y=1}^{16}\boldsymbol{V}(x,y)}{16} \tag{14}$$

where $\boldsymbol{V}(x, y)$ is the grey level at point (x, y); x is the index along x-axis.

5.2.3.3 Determining the proportion of misclassified pixels

Formulae (15) and (16) specify the calculation of α and which are the proportion of pixels misclassified respectively as valley or ridge. v_B is the number of pixels in valley region with intensity lower than DT and v_T is the total number of pixels in valley region. r_B is the number of pixels in the ridge region with intensity higher than DT and r_T is the total number of pixels in the ridge region.

$$\alpha=\frac{v_B}{v_T} \tag{15}$$

$$\beta=\frac{r_B}{r_T} \tag{16}$$

5.2.3.4 Determining the normalized ridge and valley width

The normalized valley width $\bar{W}_v$ and the normalized ridge width $\bar{W}_r$ are determined

$$\bar{W}_v=\frac{W_v}{\left(\frac{S}{125}\right)W^{\max}} \tag{17}$$

$$\bar{W}_r=\frac{W_r}{\left(\frac{S}{125}\right)W^{\max}} \tag{18}$$

where

S	is the scanner spatial sampling rate in dpi;
$W^{\max}$	is the estimated ridge or valley width for an image with 49,21 pixel per centimetre (125 pixel per inch) spatial sampling rate;
W_v and W_r	are the observed valley and ridge widths.

According to Reference [1], $W^{\max}$ = 5 is reasonable for 49,21 pixel per centimetre (125 pixel per inch) spatial sampling rate. By extension, the denominator in Formula (17) and the denominator in Formula (18) shall be 20 for a spatial sampling rate of 196,85 pixels per centimetre (500 pixels per inch).

5.2.3.5 Computing the local clarity score

The local quality score $\boldsymbol{Q}_{\mathrm{LCS}}^{local}$ is the constrained average value of α and β with a range between 0 and 1.

$$\boldsymbol{Q}_{\mathrm{LCS}}^{local}=\begin{cases}1-\dfrac{\alpha+\beta}{2}, & if\left(W_v^{nmin}<\overline{W_v}<W_v^{nmax}\right),\left(W_r^{nmin}<\overline{W_r}<W_r^{nmax}\right)\\ 0, & otherwise\end{cases} \tag{19}$$

where

W_r^{nmin} and W_v^{nmin} are the minimum values for the normalized ridge and valley width;

W_v^{nmax} and W_v^{nmax} are the maximum values for the normalized ridge and valley width.

$$W_r^{nmin} = \frac{3}{W_r} \quad (20)$$

$$W_r^{nmax} = \frac{10}{W_r} \quad (21)$$

$$W_v^{nmin} = \frac{2}{W_v} \quad (22)$$

$$W_v^{nmin} = \frac{10}{W_v} \quad (23)$$

NOTE Particular regions inherent in a fingerprint will negatively affect $\boldsymbol{Q}_{\text{LCS}}^{local}$. For example, ridge endings and bifurcations or areas with high curvature such as those commonly found in core and delta points.

5.2.3.6 LCS algorithm

For each local region ***V*** in ***I***:

a) rotate ***V*** such that dominant ridge flow is perpendicular to x-axis;

b) crop rotated ***V*** such that no invalid regions are included;

c) with ***V*** obtain the ridge-valley signature ***S*** (5.2.3.2);

d) determine DT using linear regression on ***S***;

e) for each element ***S***(x), set threshold ***T***(x) of x being ridge or valley based on DT;

f) classify columns in ***V*** as ridge (1) or valley (0) with $\boldsymbol{P}(x) = \begin{cases} 1, \text{if } \boldsymbol{S}(x) < \boldsymbol{T}(x) \\ 0, \text{otherwise} \end{cases}$;

g) determine ridge-valley transition vector ***C*** from ***P***;

h) compute the vector ***W*** containing ridge and valley widths from ***C***;

i) determine normalized ridge width and valley width $\bar{W}_r$ and $\bar{W}_v$ (5.2.3.4);

j) determine the proportion of misclassified pixels α and β (5.2.3.3);

k) compute the local quality score $\boldsymbol{Q}_{\text{LCS}}^{local}$ (5.2.3.5).