INTERNATIONAL STANDARD

ISO/IEC 19794-4

Second edition
2011-12-15

Information technology — Biometric data interchange formats —

Part 4:
Finger image data

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

Partie 4: Données d'image du doigt

Reference number
ISO/IEC 19794-4:2011(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75% of the national bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC 19794-4 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 19794-4:2005). It reflects the harmonization across the second generation of ISO/IEC 19794. Clause 8 has been technically revised and contains descriptions of the harmonized general and representation headers. Annex A is under development and will contain an amendment for conformance testing methodology for this part of ISO/IEC 19794. Annex B contains capture device certifications for capturing finger image data. Annex B has been technically revised. Annex D describes conditions for capturing finger image data, and Annex E contains the WSQ Gray-scale fingerprint image compression specification. The former Annex A “Image Quality Specification” has been removed.

ISO/IEC 19794 consists of the following parts, under the general title *Information technology — Biometric data interchange formats*:

— *Part 1: Framework*

— *Part 2: Finger minutiae data*

— *Part 3: Finger pattern spectral data*

— *Part 4: Finger image data*

— *Part 5: Face image data*

— *Part 6: Iris image data*

— *Part 7: Signature/sign time series data*

— *Part 8: Finger pattern skeletal data*

— *Part 9: Vascular image data*

— *Part 10: Hand geometry silhouette data*

— *Part 11: Signature/sign processed dynamic data*

— *Part 13: Voice data*

— *Part 14: DNA data*

Introduction

In the forensic community, the capture and transmission of fingerprint images has been a common choice for the exchange of fingerprint information used by Automatic Fingerprint Identification Systems (AFIS) for the identification of individuals. However, little to no fingerprint information is being exchanged between equipment from different vendors in the biometric user verification and access community. This has been due in part to the lack of agreement between vendors on the amount and type of information to capture, the method of capture, and the information to be exchanged.

ISO/IEC 19794 is a series of International Standards being developed by ISO/IEC JTC 1/SC 37 that supports interoperability and data interchange among biometric applications and systems. The series specifies requirements that solve the complexities of applying biometrics to a wide variety of personal recognition applications, whether such applications operate in an open systems environment or consist of a single, closed system. Additional information regarding the series is provided in ISO/IEC 19794-1.

This part of ISO/IEC 19794 is intended for those applications requiring the exchange of raw or processed fingerprint and palm images that may not necessarily be limited by the amount of resources required for data storage or transmitting time. It can be used for the exchange of scanned fingerprints containing detailed image pixel information. This part of ISO/IEC 19794 can also be used to exchange processed fingerprint image data containing considerably fewer pixels per inch and/or a lesser number of grayscale levels. This is in contrast to other parts of ISO/IEC 19794 used for exchanging lists of fingerprint characteristics such as minutiae, patterns, or other variants. These formats require considerably less storage than a fingerprint image. However, by using any of the other parts of ISO/IEC 19794, information recorded in one standard format cannot be used by algorithms designed to operate with another type of information. In other words, minutiae data records cannot be compared with pattern skeletal data comparison subsystems.

Although the minutiae, pattern, or other approaches produce different intermediate outputs, all shall initially capture a reasonably high quality fingerprint image before reducing the size of the image (in bytes) or developing a list of characteristic data from the image. Use of the captured or processed image can provide interoperability among vendors relying on minutiae-based, pattern-based or other algorithms. As a result, data from the captured finger image offers the developer more freedom in choosing or combining comparison algorithms. For example, an enrolment image may be stored on a contactless chip located on an identification document. This will allow future verification of the holder of the document with systems that rely on either minutiae-based or pattern-based algorithms. Establishment of an image-based representation of fingerprint information will not rely on pre-established definitions of minutiae, patterns or other types. It will provide implementers with the flexibility to accommodate images captured from dissimilar devices, varying image sizes, spatial sampling rates, and different grayscale depths. Use of the fingerprint image will allow each vendor to implement their own algorithms to determine whether two fingerprint records are from the same finger.

Information technology — Biometric data interchange formats —

Part 4: Finger image data

1 Scope

This part of ISO/IEC 19794 specifies a data record interchange format for storing, recording, and transmitting the information from one or more finger or palm image areas. This can be used for the exchange and comparison of finger image data. It defines the content, format, and units of measurement for the exchange of finger image data that may be used for enrolment, verification, or identification of a subject. The information consists of a variety of mandatory and optional items, including scanning parameters, compressed or uncompressed images and vendor-specific information. This information is intended for interchange among organizations that rely on automated devices and systems for identification or verification purposes based on the information from finger image areas. Information compiled and formatted in accordance with this part of ISO/IEC 19794 can be recorded on machine-readable media or may be transmitted by data communication facilities.

2 Conformance

A biometric data record conforms to this part of ISO/IEC 19794 if it satisfies all of the normative requirements related to:

a) its data structure, data values, and the relationships between its data elements, as specified throughout Clause 8 for the finger image record format of this part of ISO/IEC 19794;

b) the relationship between its data values and the input biometric data from which the biometric data record was generated, as specified throughout Clause 8 for the finger image record format of this part of ISO/IEC 19794.

A system that produces biometric data records is conformant to this part of ISO/IEC 19794 if all biometric data records that it outputs conform to this part of ISO/IEC 19794 (as defined above) as claimed in the Implementation Conformance Statement (ICS) associated with that system. A system does not need to be capable of producing biometric data records that cover all possible aspects of this part of ISO/IEC 19794, but only those that are claimed to be supported by the system in the ICS.

A system that uses biometric data records is conformant to this part of ISO/IEC 19794 if it can read, and use for the purpose intended by that system, all biometric data records that conform to this part of ISO/IEC 19794 (as defined above) as claimed in the ICS associated with that system. A system does not need to be capable of using biometric data records that cover all possible aspects of this part of ISO/IEC 19794, but only those that are claimed to be supported by the system in an ICS.

3 Normative references

The following referenced documents are indispensable for the application 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 10918-1, *Information technology — Digital compression and coding of continuous-tone still images: Requirements and guidelines*

ISO/IEC 15444 (all parts), *Information technology — JPEG 2000 image coding system*

ISO/IEC 15948, *Information technology — Computer graphics and image processing — Portable Network Graphics (PNG): Functional specification*

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*

4 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19794-1 and the following apply.

4.1
capture device spatial sampling rate
number of pixels per unit distance used by a sensor or scanning device to initially capture an image

4.2
fingerprint image
area of friction skin on the fleshy surface of a finger located horizontally between the two edges of the fingernail and vertically between the first joint and the tip of a finger

NOTE It contains a unique pattern of friction ridge and valley information commonly referred to as a “fingerprint”.

4.3
image spatial sampling rate
number of pixels per unit distance in the image

NOTE This may be the result of processing a captured image. The original captured scanned image may have been subsampled, scaled, down-sampled, or otherwise processed.

4.4
palm
friction ridge skin on the side and underside of the hand

4.5
plain fingerprint image
image captured from a finger placed on a platen without any rolling movement

4.6
rolled fingerprint image
image captured that is located between the two edges of the fingernail

NOTE This type of image is typically acquired using a rolling motion from one edge of the fingernail to the other.

4.7
vertical rolls
fingerprint images that have been captured by rolling a finger vertically from the slap position over the finger tip to the nail

NOTE This is in contrast to horizontal rolls, which are captured by horizontal rolling from the nail over the slap position to the other side of the nail as described in the definition for “rolled fingerprint image”.

5 Abbreviated terms

For the purposes of this document the following abbreviations and those given in ISO/IEC 19794-1 apply.

ppcm pixels per centimetre

ppi pixels per inch

TIR Total Internal Reflection

6 Data conventions

6.1 Byte and bit ordering

Each item of information, field, or logical record shall contain one or more bytes of data. Within a record all multibyte quantities are represented in Big-Endian format. That is, the more significant bytes of any multibyte quantity are stored at lower addresses in memory than less significant bytes. The order for transmission shall also be the most significant byte first and least significant byte last. Within a byte, the order of transmission shall be the most significant bit first and the least significant bit last. All numeric values are fixed-length unsigned integer quantities.

6.2 Scan sequence

It is not the purpose of this part of ISO/IEC 19794 to specify the orientation of the finger (or palm), the method of scanning, or the order of scanning used to capture the image. However, each image as presented in accordance with this format standard shall appear to have been captured in an upright position and approximately centered horizontally in the field of view. The recorded image data shall appear to be the result of a scanning of an impression of a fingerprint. The scanning sequence (and recorded data) shall appear to have been captured from left-to-right, progressing from top-to-bottom of the fingerprint or palm print. Figure 1 illustrates the recording order for the scanned image. For the purpose of describing the position of each pixel within an image to be exchanged, a pair of reference axes shall be used. The origin of the axes, pixel location (0,0), shall be located at the upper left-hand corner of each image. The x-coordinate (horizontal) position shall increase positively from the origin to the right side of the image. The y-coordinate (vertical) position shall increase positively from the origin to the bottom of the image.

7 Image acquisition requirements

7.1 General

Image capture requirements are dependent on various factors including the application, the available amount of raw pixel information to retain or exchange, and targeted performance metrics. As a result of these factors, the image capture operation will be associated with a combination of image acquisition parameters settings described below.

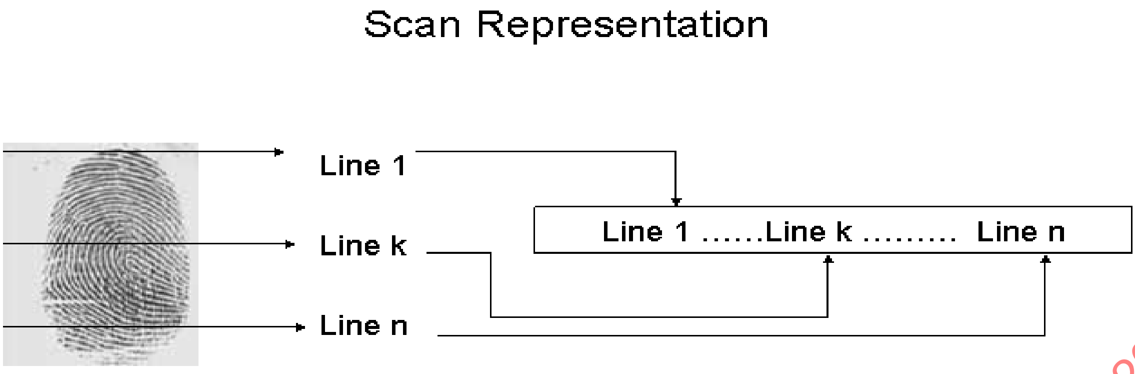

Figure 1 — Order of scanned lines

7.2 Pixel aspect ratio

The finger image shall be represented using square pixels, in which the horizontal and vertical dimensions of the pixels are equal. Any difference between these two dimensions should be within 1%. That is, the ratio of horizontal to vertical pixel dimensions should be between 0,99 and 1,01.

7.3 Bit-depth

The grayscale precision of the pixel data shall be specified in terms of the bit-depth or the number of bits used to represent the grayscale value of a pixel. A bit-depth of 3 provides 8 levels of grayscale; a depth of 8 provides 256 levels of gray. For grayscale data, the minimum value that can be assigned to a "black" pixel shall be zero. The maximum value that can be assigned to a "white" pixel shall be the grayscale value with all of its bits of precision set to "1". However, the "blackest" pixel in an image may have a value greater than "0" and the "whitest" pixel may have a value less than its maximum value. For example, the range of values for a "white" pixel with 5 bits of precision shall be 31 or less. The range of values for a "white" pixel using 8 bits of precision shall be 255 or less. The bit-depth may range from 1 to 16 bits.

7.4 Grayscale data

Grayscale finger image data shall be stored, recorded, or transmitted in either compressed or uncompressed form. The image data portion of a record for an uncompressed grayscale image shall contain a set of raw pixel information. Using a bit-depth of 8 bits (256 grayscale levels) each pixel shall be contained in a single byte. Pixel values with a depth of less than eight bits shall be stored and transmitted in a packed binary format. Increased precision for pixel values greater than 255 shall use two unsigned bytes to hold up to sixteen-bit pixels with values in the range of 0-65535. The encoding of a compressed grayscale image shall be the output of the appropriate grayscale compression algorithm specified in Table 9. Upon decompression the grayscale value for each pixel shall be represented in the same manner as pixels in an uncompressed image.

7.5 Dynamic range

The image grayscale shall be encoded using the agreed precision necessary to meet the dynamic range requirement for a specific application. It is assumed that the precise requirements of the application are known.

7.6 Capture device spatial sampling rate

Grayscale fingerprint images to be captured shall be acquired by an image capture device operating at a specific scanning spatial sampling rate. As the spatial sampling rate used in the image capture process is increased, more detailed ridge and structure information for processing becomes available. For minutiae and small feature based algorithms, use of the higher spatial sampling rate enhances the detection of more closely spaced features that may not be detected using the minimum spatial sampling rate.

7.7 Image spatial sampling rate

The spatial sampling rate of the image data formatted and recorded for interchange may be the scan spatial sampling rate of the image or it may have been sub-sampled, scaled, down-sampled, or otherwise processed to produce a form for representing the ridge and valley structure areas of the fingerprint.

7.8 Fingerprint image location

This part of ISO/IEC 19794 is designed to accommodate both plain (flat) or rolled fingerprint images. Biometric systems perform better if the volar pad of the finger is centered both horizontally and vertically in the image capture area. Therefore, when capturing a fingerprint image, the center of the fingerprint image should be located in the approximate center of the image capture area.

For multiple finger verification and/or identification purposes, there are currently fingerprint scanner devices that will acquire images of multiple fingers during a single capture cycle. These devices are capable of capturing the plain impressions from two, three, or four adjacent fingers of either hand during a single scanning. The plain impressions from the two thumbs or two index fingers can also be captured at one time. Therefore, with three placements of the fingers on a device's scanning surface all ten fingers from an individual shall be acquired in three scans – right four fingers, left four fingers, and two thumbs. For these multi-finger captures, half of the captured fingers should be located to the left of the image center and the other half of the fingers to the right of the image center.

7.9 Palm image location

This part of ISO/IEC 19794 is also designed to accommodate images from the palm of the hand or from the side of the hand opposite the thumb also known as the "writer's palm". Most comparison subsystems perform better if the flat or fleshy part of the palm or writer's palm is centered both horizontally and vertically in the image capture area. Therefore, when capturing a palmprint image, the center of the palm or writer's palm image area should be located in the approximate center of the image capture area. The palm itself may be captured as one entity, or various pieces of it can be captured as single images such as the thenar (fleshy part behind the thumb), hyperthenar (fleshy area opposite the thumb), or interdigital (area of the palm directly beneath the four fingers).

8 Finger image record format

8.1 Record structure

This part of ISO/IEC 19794 defines the composition of the finger image record. Each record shall pertain to a single subject and shall contain at least one representation for each of one or more fingers, multiple fingers (single image records), or palms. Figure 2 illustrates the record structure for the finger image record format.

Figure 3 details the order of fields in the record and the length of each field. The fields in white indicate mandatory fields. Shaded fields indicate optional information.

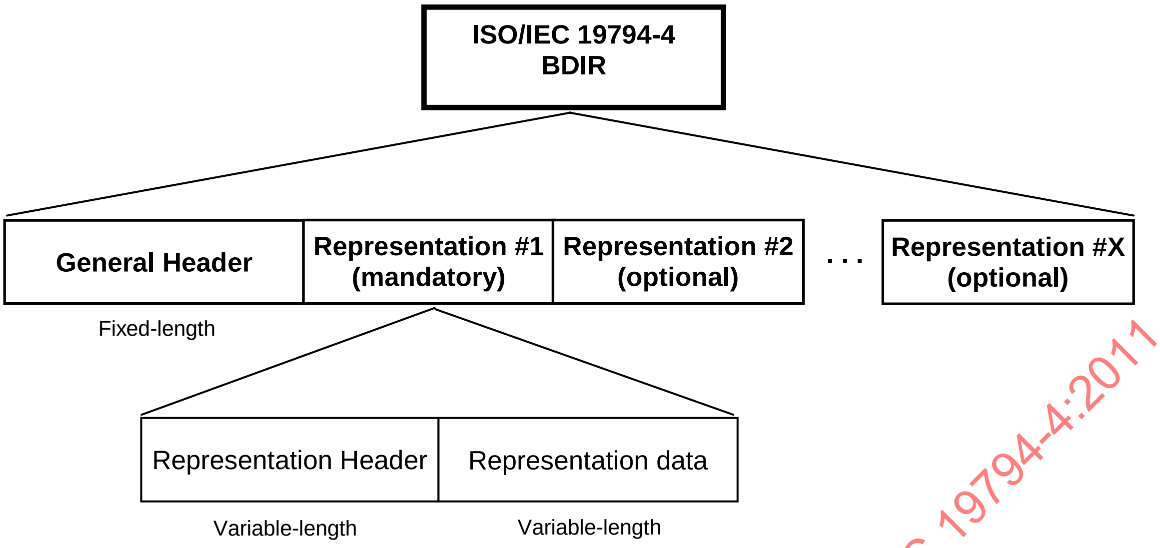

Figure 2 — Finger image record structure

The organization of the record format is as follows:

- A single fixed-length (16-byte) general record header containing information about the overall record, including the number of finger/palm images represented and the overall record length in bytes;
- A single finger record for each single finger, multi-finger, or palm image representation consisting of:
  - o A variable length finger image representation header containing information pertaining to the data for a single finger, multi-finger, or palm image;

    NOTE1 For each quality block of information recorded, the length will be increased by 5 bytes.
    NOTE2 If any of the finger image representations contain a device certification block, then the length of each finger representation header shall be a minimum of a 42-byte header.
    NOTE3 For each device certification block of information recorded the length will be increased by 3 bytes.

  - o A variable-length finger image representation body containing
    - ▪ Compressed or uncompressed image data representation for a single, multi-finger, or palm image; and
    - ▪ Optional extended data describing finger segmentation (in the case of multi-finger images), annotation, and comments.

Annex C provides an example of the application of this part of ISO/IEC 19794. It illustrates the completion of required data fields for both the general record header and the finger image record.

8.2 Finger image general header

8.2.1 Required fields

Table 1 lists the fields included in the general record header. As this is a fixed-length header, information shall be included for each field within the header.

General Header	Format identifier	Version number	Length of record	Number of finger/palm representations	Certification flag	Number of distinct finger/palm positions
	4	4	4	2	1	1

Representation Header	Representation length	Capture date & time	Capture device technology identifier	Capture device vendor Identifier	Capture device type identifier	Number of quality blocks
	4	9	1	2	2	1

Quality block data	Number of certification blocks	Certification block data	Finger/palm position	Representation number	Scale units	Capture device spatial sampling rate (horiz)	Capture device spatial sampling rate (vert)
5x	1	3x	1	1	1	2	2

Image spatial sampling rate (horiz)	Image spatial sampling rate (vert)	Bit-depth	Image compression algorithm	Impression type	Horizontal line length	Vertical line length	Image data length
2	2	1	1	1	2	2	4

Quality block data	Quality score	Quality algorithm vendor ID	Quality algorithm ID
	1	2	2

Certification block data	Certification authority identifier	Certification scheme identifier
	2	1

Representation Body	Image data	Extended data blocks
	Variable	Variable

Extended data block	Type identification code	Length of data	Data section
	2	2	Variable

Figure 3 — Order and size of fields in the finger image record

8.2.2 Format identifier

The format identifier shall be recorded in four bytes. The format identifier shall consist of three characters "FIR" followed by a zero byte as a NULL string terminator.

8.2.3 Version number

The number for the version of this part of ISO/IEC 19794 used for constructing the BDIR shall be placed in four bytes. This version number shall consist of three ASCII numerals followed by a zero byte as a NULL

Table 1 — General record header

Field	Size	Valid values	Notes
Format identifier	4 bytes	464952_{Hex} ('F' 'I' 'R' 00_{Hex})	"FIR" – Finger Image Record
Version number	4 bytes	30323000_{Hex} ('0' '2' '0' 00_{Hex})	"020"
Length of record	4 bytes	57 to (2^{32}-1)	Includes all finger/palm representations, quality blocks and certification blocks[1)]
Number of finger/palm representations	2 bytes	1 to 672	[(14 finger positions) + (11 multiple finger positions) + (17 palm codes)]* 16 = 672 possible representations
Certification flag	1 byte	0, 1	Indicates the presence of any device certification blocks within the representation headers
Number of distinct fingers/palm positions	1 byte	>=1	Number of fingers or palms represented

string terminator. The first and second character will represent the major version number and the third character will represent the minor revision number. Upon approval of this specification, the version number shall be "020" – Version 2 revision 0.

8.2.4 Length of record

The length (in bytes) of the entire BDIR shall be recorded in four bytes. This count shall be the total length of the BDIR including the general record header and one or more representation records. The length of the record is dependent on several factors.

8.2.5 Number of finger/palm representations

The total number of representation records contained in the BDIR shall be recorded in two bytes. A minimum of one representation is required. In cases where there is more than one representation of any finger or palm, this number will be greater than the number of fingers or palms.

8.2.6 Device certification flag

The one-byte certification flag shall indicate whether each representation header includes a certification record. A value of 00_{Hex} shall indicate that none of the representations contains a certification record. A value of 01_{Hex} shall indicate that all representations contain a certification record.

NOTE A certification record that is present may contain 0 certifications (in that case the number-of-certifications field in the certification record has the value 0).

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1) If Certification flag (General Header) = 0

$$\text{Length} = 16 + \sum_{1}^{\text{Number of Representations}} (41 + 5*(\#QualityBlocks) + SizeOfImageData + SizeOfExtendedData)$$

If Device Certification Flag (General Header) = 1

$$\text{Length} = 16 + \sum_{1}^{\text{Number of Representations}} (42 + 5*(\#QualityBlocks) + 3*(\#Certification\ blocks) + SizeOfImageData + SizeOfExtendedData$$

8.2.7 Number of distinct finger/palm positions

The number of fingers or palms included in the record shall be recorded in one byte. Multiple fingers acquired by a single capture and contained in the same image are counted as a single finger image.

EXAMPLE 1 If a record contains two images of a right index finger (position code 2 in Table 6) and two images of a left index finger (position code 7 in Table 6) then the value encoded by this clause would be 2. The number of representations encoded by clause 8.2.5 would be 4.

EXAMPLE 2 If a record contains two images of a right index finger (position code 2 in Table 6), one image of the left index and middle fingers (position code 43 in Table 7), and one image of the right four fingers (position code 13 in Table 6) then the value encoded by this clause would be 3. The number of representations encoded by clause 8.2.5 would be 4.

8.3 Finger/palm image representation header

8.3.1 Required fields

A finger or palm representation header shall start each section of finger data providing information for that representation of a single finger image, multi-finger image, or palm image. For each such image there shall be one finger header record accompanying the representation of the image data. The finger header shall occupy a minimum of 41 or 42 bytes as described below (depending on the certification flag in the general header). The compressed or uncompressed image data for that image representation shall immediately follow the header portion. Additional representations (including the header portion) will be concatenated to the end of the previous representation data. Table 2 is a list of the entries contained in the header preceding each block of finger/palm image data. Table 3 lists the finger/palm image data and various types of extended data associated with a finger representation.

Table 2 — Finger image representation header record

Field	Size	Valid values	Notes
Representation length	4 bytes	41 $_{Hex}$ to FFFFFFFF $_{Hex}$	Denotes the length in bytes of the representation including the representation header fields
Capture date and time	9 bytes	See ISO/IEC 19794-1	The capture date and time field shall indicate when the capture of this representation stated in Coordinated Universal Time (UTC). The capture date and time field shall consist of 9 bytes. Its value shall be encoded in the form given in ISO/IEC 19794-1.
Capture device technology identifier	1 byte	0 to 20	The capture device technology ID shall be encoded in one byte. This field shall indicate the class of capture device technology used to acquire the captured biometric sample. A value of 00Hex indicates unknown or unspecified technology. See Table 4 for the list of possible values.
Capture device vendor identifier	2 bytes	0000 $_{Hex}$ to FFFF $_{Hex}$	The capture device vendor identifier shall identify the biometric organization that owns the product that created the BDIR. The capture device algorithm vendor identifier shall be encoded in two bytes carrying a CBEFF biometric organization identifier (registered by IBIA or other approved registration authority). A value of all zeros shall indicate that the capture device vendor is unreported.

Field	Size	Valid values	Notes
Capture device type identifier	2 bytes	0000 $_{Hex}$ to FFFF $_{Hex}$	The capture device type identifier shall identify the product type that created the BDIR. It shall be assigned by the registered product owner or other approved registration authority. A value of all zeros shall indicate that the capture device type is unreported. If the capture device vendor identifier is 0000$_{Hex}$, then also the capture device type identifier shall be 0000$_{Hex}$.
Quality record	1 to 1,276 bytes (1 to 1 + (255 * 5))	See Table 5 in ISO/IEC 19794-1:2011 for more details	A quality record shall consist of a length field followed by zero or more quality blocks. The length field shall consist of one byte. It shall represent the number of quality blocks as an unsigned integer. Each quality block shall consist of – a quality score, – a quality algorithm vendor identifier, and – a quality algorithm identifier. A quality score should express the predicted comparison performance of a representation. A quality score shall be encoded in one byte as an unsigned integer. Allowed values are – 0 to 100 with higher values indicating better quality, – 255, i.e. ff$_{Hex}$, for indicating that an attempt to calculate a quality score failed. The quality algorithm vendor identifier shall identify the provider of the quality algorithm. The quality algorithm vendor identifier shall be encoded in two bytes carrying a CBEFF biometric organization identifier (registered by IBIA or other approved registration authority). A value of all zeros shall indicate that the value for this field is unreported. The quality algorithm identifier shall identify the vendor's quality algorithm that created the quality score. It shall be assigned by the provider of the quality algorithm or an approved registration authority. The quality algorithm identifier shall be encoded in two bytes. A value of all zeros shall indicate that the value for this field is unreported.
Certification record	0 to 766 bytes (1 to 1 + (255 * 3))	See ISO/IEC 19794-1	The certification record only exists if the certification flag in the general header has a value of 1. A certification record shall consist of a length field followed by zero or more certification blocks. The length field shall consist of one byte. It shall represent the number of unique certification blocks as an unsigned integer.

Field	Size	Valid values	Notes
			Each certification block shall consist of – a certification authority identifier and – a certification scheme identifier. The certification authority identifier shall identify a certification authority that has carried out a certification according to a certification scheme. The certification authority identifier shall be encoded in two bytes carrying a CBEFF biometric organization identifier (registered by IBIA or other approved registration authority). The certification scheme identifier shall identify a certification scheme according to which a certification has been carried out. The certification scheme identifier shall be encoded in one byte. See Table 5 for the list of certification scheme identifiers.
Finger/palm position	1 byte	0 to 10; 13 to 15; 20 to 36; 40 to 50	See Table 6 through 9
Representation number	1 byte	0 to 15	
Scale units	1 byte	1 to 2	Pixels/Inch or pixels/cm
Scan spatial sampling rate (horiz)	2 bytes	0 to (2^{16}-1)	Dependent upon the scanner
Scan spatial sampling rate (vert)	2 bytes	0 to (2^{16}-1)	Dependent upon the scanner
Image spatial sampling rate (horiz)	2 bytes	<= Scan Spatial sampling rate (horiz)	Quality level dependent
Image spatial sampling rate (vert)	2 bytes	<= Scan Spatial sampling rate (vert)	Quality level dependent
Bit-depth	1 byte	1 to 16 bits	2 – 65535 gray levels
Image compression Algorithm	1 byte	0 to 5	See Table 9
Impression type	1 byte	0 to 15; 20 to 29	See Table 10
Horizontal line length	2 bytes	0 to (2^{16}-1)	Dependent on the sensor used
Vertical line length	2 bytes	0 to (2^{16}-1)	Dependent on the sensor used
Image data length	4 bytes	0 to (2^{32}-58)	Number of bytes for the compressed/uncompressed image data

8.3.2 Representation length

The representation-length field denotes the length in bytes of the representation including the representation header fields.

Table 3 — Image and extended data

Data Type	Field	Size	Valid Values	Notes
Image Data	Finger/palm image data	< 2^{32} -1 bytes	____________	Compressed or uncompressed image data
Extended Data Blocks	Type identification code	2 bytes	0001_{Hex} to $FFFF_{Hex}$	Segmentation, annotation, comment, or vendor specific data
	Length of data	2 bytes	0004_{Hex} to $FFFF_{Hex}$	
	Data section	(Length of data)-4 bytes		Values >0100_{Hex} are vendor specific extended data

8.3.3 Capture date-time

The capture date and time field shall indicate when the capture of this representation started in Coordinated Universal Time (UTC). This field is not intended to encode the time the record was instantiated. The capture date and time field shall be encoded in accordance to the requirements given in ISO/IEC 19794-1.

8.3.4 Capture device technology ID

The capture device technology ID shall be encoded in one byte. This field shall indicate the class of capture device technology used to acquire the captured biometric sample. See Table 4 for a list of capture device technologies. A value of 00_{Hex} indicates unknown or unspecified technology.

Table 4 — Capture device technology

ID	Capture device technology
0	Unknown or unspecified
1	White light optical TIR
2	White light optical direct view on platen *Note: Card scanner should encode their technology type as "white light optical direct view on platen"*
3	White light optical touchless
4	Monochromatic visible optical TIR
5	Monochromatic visible optical direct view on platen
6	Monochromatic visible optical touchless
7	Monochromatic IR optical TIR
8	Monochromatic IR optical direct view on platen
9	Monochromatic IR optical touchless
10	Multispectral optical TIR
11	Multispectral optical direct view on platen
12	Multispectral optical touchless
13	Electro luminescent
14	Semiconductor capacitive
15	Semiconductor RF
16	Semiconductor thermal
17	Pressure sensitive
18	Ultrasound
19	Mechanical
20	Glass fiber

8.3.5 Capture device vendor identifier

The capture device vendor identifier shall identify the biometric organization that owns the product that created the BDIR. The capture device algorithm vendor identifier shall be encoded in two bytes carrying a CBEFF biometric organization identifier (registered by IBIA or other approved registration authority). A value of all zeros shall indicate that the capture device vendor is unreported.

8.3.6 Capture device type identifier

The capture device type identifier shall identify the product type that created the BDIR. It shall be assigned by the registered product owner or other approved registration authority. A value of all zeros shall indicate that the capture device type is unreported.

8.3.7 Finger/palm image quality

8.3.7.1 General

The quality information of the overall finger image data shall be recorded in one or more five-byte blocks. Each of these blocks shall pertain to a specific quality/vendor/algorithm evaluation. Figure 4 illustrates the placement and recording of multiple quality blocks.

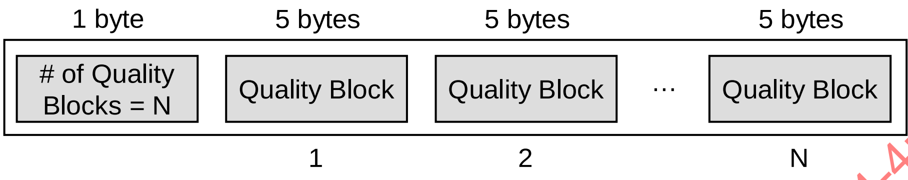


Figure 4 — Image quality layout

8.3.7.2 Number of quality Blocks

The first byte is mandatory and shall contain the number of blocks of quality information of the overall finger image data. Subsequent 5-byte blocks shall contain the specific quality/vendor/algorithm information for each quality/vendor/algorithm evaluation. A value of zero (0) means that no attempt was made to assign a quality score. In this case, no Quality Blocks are present.

8.3.7.3 Quality score

The quality score, as defined in ISO/IEC 29794-1, shall be recorded in the first byte of each of the five-byte blocks. It shall be a quantitative expression of the predicted verification performance of the biometric sample. Valid values for Quality Score are integers between 0 and 100, where higher values indicate better quality. A value of 255 is to handle a special case that indicates a failed attempt to calculate a quality score.

8.3.7.4 Quality algorithm vendor ID

To enable the recipient of the quality score to differentiate between quality scores generated by different algorithms, the provider of quality scores shall be uniquely identified by the next two bytes. This Vendor ID shall be registered with the International Biometrics Industry Association (IBIA).

8.3.7.5 Quality algorithm ID

The remaining two bytes shall specify an integer product code assigned by the vendor of the Quality Algorithm ID. It indicates which of the vendor's algorithms (and version) was used in the calculation of the quality score and shall be within the range of 0 to 65535. Multiple quality scores calculated by the same algorithm (same vendor ID and algorithm ID) shall not be present in a single representation.

8.3.8 Capture device certifications

8.3.8.1 General

This multi-byte block contains information to indicate the compliant certification procedures that were used to test the biometric capture equipment used. The certification record shall consist of a length field followed by zero or more 3-byte certification blocks. Each certification block shall consist of a certification authority identifier, and a certification scheme identifier.

If the device certification flag in the general header has a value of 00_{Hex}, no capture device certification information shall be present in any of the representation header records for that finger image record.

8.3.8.2 Number of certifications

The first byte is mandatory and shall contain the number of certification blocks as an unsigned integer for the capture device.

8.3.8.3 Certification authority ID

The first two bytes of each block contain the CBEFF biometric organization identifier of the certification authority (registered by IBIA or other approved registration authority). This is the agency that certifies a device according to a particular certification scheme identifier.

8.3.8.4 Certification scheme identifier

This last byte of the block shall identify a certification scheme used to certify the capture device. A list of current certification scheme identifiers is contained in Table 5.

Table 5 — Identifiers for certification schemes specified in the annexes

Certification scheme Identifier	Annex
00_{Hex}	Reserved by SC 37 for future use
01_{Hex}	0 — Image quality specification for AFIS systems
02_{Hex}	0 — Image quality specification for personal verification
03_{Hex}	0 — Requirements and test procedures for optical fingerprint scanners
04_{Hex} to FF_{Hex}	Reserved by SC 37 for future use

8.3.9 Finger/palm position

This 1-byte field shall contain the finger/palm position code. Code 0 is reserved for an unknown finger or fingers. Codes 1-10 from Table 6 should be used for single fingers. Codes 13 and 14 are used for the images containing four fingers from the right hand and left hand respectively. Table 7 lists finger position codes for common 2-finger and 3-finger combinations. Code 15 accommodates the simultaneous capture of two thumbs, while code 46 accommodates the simultaneous capture of the two index fingers. For multiple-finger captures that have missing fingers the extended data annotation may be used (See Clause 8.4.4).

Codes for palm images are found in Table 8. For full palms the captured area should extend from the "wrist bracelet" through the second joint of the fingers. Similarly, the captured area of the upper palm should extend from immediately below the interdigital area through the second joint of the fingers. The lower palm will cover the area from the "wrist bracelet" through the interdigital area.

8.3.10 Representation number

This one byte field shall contain the specific image representation number associated with the image data (finger, multi-finger or palm image data).

8.3.11 Scale units

This field shall specify the units used to describe the scanning and image spatial sampling rates of the image. A 01_{Hex} in this field indicates pixels per inch, or a 02_{Hex} indicates pixels per centimeter.

NOTE This field refers to the metric inch that is not an ISO metric. The intention was to enable entries in fields according to Clause 8.3.12 to Clause 8.3.15 that are integer numbers (e.g. 500 dpi) and to avoid for many existing systems floating point numbers in or rounding errors of the corresponding value in the metric system.

Table 6 — Finger position codes

Finger position	Finger code
Unknown	0
Right thumb	1
Right index finger	2
Right middle finger	3
Right ring finger	4
Right little finger	5
Left thumb	6
Left index finger	7
Left middle finger	8
Left ring finger	9
Left little finger	10
Plain right four fingers	13
Plain left four fingers	14
Plain thumbs (2)	15

Table 7 — Multiple finger position codes

Finger position	Finger code
2-Finger Combinations	
Right index and middle	40
Right middle and ring	41
Right ring and little	42
Left index and middle	43
Left middle and ring	44
Left ring and little	45
Right index and Left index	46
3-Finger Combinations	
Right index and middle and ring	47
Right middle and ring and little	48
Left index and middle and ring	49
Left middle and ring and little	50

8.3.12 Capture device spatial sampling rate (horizontal)

This 2-byte field shall specify the rounded scanning spatial sampling rate used in the horizontal direction. The scale units field will determine whether the value is pixels per inch or pixels per centimeter.

8.3.13 Capture device spatial sampling rate (vertical)

This 2-byte field shall specify the rounded scanning spatial sampling rate used in the vertical direction. The scale units field will determine whether the value is pixels per inch or pixels per centimeter.

Table 8 — Palm codes

Palm position	Palm code
Unknown palm	20
Right full palm	21
Right writer's palm	22
Left full palm	23
Left writer's palm	24
Right lower palm	25
Right upper palm	26
Left lower palm	27
Left upper palm	28
Right other	29
Left other	30
Right interdigital	31
Right thenar	32
Right hypothenar	33
Left interdigital	34
Left thenar	35
Left hypothenar	36

8.3.14 Image spatial sampling rate (horizontal)

This 2-byte field shall specify the rounded image spatial sampling rate used in the horizontal direction. The scale units field will determine whether the value is pixels per inch or pixels per centimeter. It should be noted that certain combinations of scan and image pixel spatial sampling rate values may result in overlapping pixels or spaces between pixels in the captured image.

8.3.15 Image spatial sampling rate (vertical)

This 2-byte field shall specify the rounded image spatial sampling rate used in the vertical direction. The scale units field will determine whether the value is pixels per inch or pixels per centimetre. It should be noted that certain combinations of scan and image pixel spatial sampling rate values may result in overlapping pixels or spaces between pixels in the captured image.

8.3.16 Bit-depth

This 1-byte field shall contain the number of bits used to represent a pixel. This field shall contain an entry of 01_{Hex} to 10_{Hex}.

8.3.17 Image compression algorithm

This 1-byte field shall specify the method used to record the uncompressed or compressed grayscale images. Table 9 lists the available storage options and compression algorithms that may be used. Uncompressed image data shall be recorded in an unpacked or packed form. When using the unpacked option for grayscale pixels greater than eight bits, each pixel shall be recorded in a pair of bytes right justified.

When the compression algorithm code is 2, a certified version of the Wavelet Scalar Quantization (WSQ) algorithm as described in Annex E shall be used to compress 8-bit, 197 ppcm (500 ppi) grayscale images, and shall be limited to a 15:1 compression ratio[2]. WSQ shall not be used to compress images scanned at 394 ppcm (1000 ppi).

2) Certification information for the WSQ algorithm can be found at http://fingerprint.nist.gov/wsq.

Table 9 — Compression algorithm codes

Code	Compression Algorithm	Normative Reference	Allowed Spatial Sampling
0	None – No bit-packing	N/A	All
1	None – Bit packed	N/A	All
2	WSQ	IAFIS_IC-0110 Annex E	197 ppcm
3	JPEG (lossy)	ISO/IEC 10918-1	For legacy data 197 ppcm only
4	JPEG 2000 (lossy)	ISO/IEC 15444	394 ppcm
5	JPEG 2000 (lossless)	ISO/IEC 15444	197 ppcm or 394 ppm
6	PNG	ISO/IEC 15948	All

The compression algorithm code of 3 indicates that the JPEG compression algorithm as described in ISO/IEC 10918-1 has also been used to compress the 8-bit, 197 ppcm (500 ppi) grayscale images. However, JPEG shall not be used for new applications. It is retained in this part of ISO/IEC 19794 to allow previously collected JPEG images to be encoded.

When the compression algorithm code is 4, fingerprint/palmprint images scanned at 394 ppcm (1000 ppi) with a bit-depth of 8 bits, shall be compressed using the JPEG 2000 algorithm as described in ISO/IEC 15444. When this algorithm is used, then the JPEG 2000 profile settings as specified in the "Profile for 1000ppi Fingerprint Compression" should be incorporated. For the case where the compression algorithm code is 5 then the ISO/IEC 15948 PNG algorithm shall be used to compress the image.

NOTE The recommendation is that JPEG 2000 compression be limited to 15:1 for 394 ppcm (1000 ppi) images. This compression ratio should be considered as a maximum value and where bandwidth and/or storage permits, lower levels of compression will result in higher quality images, especially where devices with smaller image sensors are used. Images scanned at 197 ppcm (500 ppi), if compressed should use WSQ compression and the compression ratio shall be limited to 15:1; above 197 ppcm (500 ppi), JPEG 2000 compression is recommended. No recommendations are being made for compression of other image spatial sampling rates.

8.3.18 Impression type

The impression type of the finger or palm image shall be recorded in this one byte field. The codes for this byte are defined in Table 10. Nonlive entries refer to images scanned from cards or other media. Live-scan contactless refers to image capture devices that do not depend upon the surface of a finger making contact with a scanner platen.

8.3.19 Horizontal line length

This two-byte binary field shall be used to specify the number of pixels contained on a single horizontal line of the transmitted image.

Table 10 — Finger and palm impression codes

Code	Description
0	Live-scan plain
1	Live-scan rolled
2	Nonlive-scan plain
3	Nonlive-scan rolled
4	Latent impression
5	Latent tracing
6	Latent photo
7	Latent lift
8	Live-scan swipe
9	Live-scan vertical roll
10	Live-scan palm
11	Nonlive-scan palm
12	Latent palm impression
13	Latent palm tracing
14	Latent palm photo
15	Latent palm lift
20	Reserved by SC 37 for future use
21	Reserved by SC 37 for future use
22	Reserved by SC 37 for future use
23	Reserved by SC 37 for future use
24	Live-scan optical contactless plain
25	Reserved by SC 37 for future use
26	Reserved by SC 37 for future use
27	Reserved by SC 37 for future use
28	Other
29	Unknown

8.3.20 Vertical line length

This two-byte binary field shall be used to specify the number of horizontal lines contained in the transmitted image.

8.3.21 Image data length

This 4-byte field shall contain the length (expressed as the number of bytes) of the compressed or uncompressed image data contained in this representation. It is used to provide a pointer around the compressed image data to the first byte in the extended data field or to the next representation.

8.3.22 Finger/palm image data

This field shall contain the grayscale image data formatted and recorded in accordance with the image compression algorithm.

8.4 Extended data

8.4.1 Extended data block function

This clause of the finger representation is open to placing additional data that may be used by the comparison system. The size of this section shall be kept as small as possible, augmenting the image data stored in the standard image data section. The extended data for each finger representation shall immediately follow the standard image data for that finger representation. More than one extended data area may be present for each finger representation. The individual extended data length fields are used as indices to parse the extended data.

NOTE The extended data area cannot be used alone, without the standard portion of the Image record.

While the extended data area allows for inclusion of proprietary data within the image format, this is not intended to allow for alternate representations of data that can be represented in open manner as defined in this part of ISO/IEC 19794. The intention of this part of ISO/IEC 19794 is to provide interoperability.

8.4.2 Extended data block structure

8.4.2.1 Type identification code

This field shall have a length of two bytes. It shall identify the format of the extended data area when this area is present. A value of zero in both bytes is a reserved value and shall not be used. A value of zero in the first byte, followed by a non-zero value in the second byte, shall indicate that the extended data section has a format defined in this part of ISO/IEC 19794; currently, only segmentation, annotation, and comment formats are specified (refer to clauses 8.4.3, 8.4.4, and 8.4.5). A non-zero value in the first byte shall indicate a vendor-specified format with a code maintained by the vendor. Refer to Table 11 for a summary of the Extended Data Area Type Identification Codes.

Table 11 — Extended data area type codes

First byte	Second byte	Identification
00_{Hex}	00_{Hex}	Reserved by SC 37 for future use
00_{Hex}	01_{Hex}	Segmentation
00_{Hex}	02_{Hex}	Annotation
00_{Hex}	03_{Hex} to FF_{Hex}	Comment
01_{Hex} to FF_{Hex}	00_{Hex} to FF_{Hex}	Vendor specific extended data

8.4.2.2 Length of data

The length of the extended data section shall be recorded in two bytes. This value is used to skip to the next extended data type identification field if the comparison subsystem cannot decode or use this data. This length field includes the count of the length and type identification fields (four bytes total).

8.4.2.3 Data section

The data field of the extended data is defined and formatted by the type identification code used by the equipment that is generating the finger image record, or by common extended data formats contained in this part of ISO/IEC 19794 for segmentation, annotation, or comment.

8.4.3 Segmentation data format

If the extended data type identification code is 0001_{Hex}, the extended data section contains segmentation and image quality data for each segment of the flat fingerprint image. This extended data section provides a measure of estimated correctness regarding the accuracy of the location of the segmented finger(s) within the multi-finger slap image, information regarding the image quality for each of the segmented fingers, and the locations for each of the image segments of the individual fingers. Table 12 lists the required fields for the segmentation extended data section.

8.4.3.1 Segmentation quality assessment algorithm owner and algorithm ID

The value of the segmentation shall be interpreted in view of the method used to assess the correctness of the segmentation. Therefore, the segmentation quality assessment algorithm's supplier (owner) and specific identity (ID) are contained in the next four bytes. The segmentation quality assessment algorithm owner's ID is the 16-bit format owner value assigned by the IBIA. The last two bytes shall contain a specific identifier for the segmentation quality assessment algorithm. This field contains the binary representation of the integer product code and should be within the range 1 to 65535. This value is assigned by the algorithm owner, who may also choose to register it with the IBIA. Values of all 00_{Hex} for each of these bytes indicate that segmentation owner and algorithm ID are unreported.

Table 12 — Segmentation data

<table>
<tr><th colspan="3">Field</th><th>Section</th><th>Size</th><th>Valid Values</th><th>Notes</th></tr>
<tr><td colspan="3">Segmentation quality assessment algorithm owner and algorithm ID</td><td>8.4.3.1</td><td>4 Bytes</td><td></td><td>Segmentation quality assessment algorithm owner and algorithm ID IBIA Assigned;
Owner Assigned algorithm ID (Optional IBIA Registered)</td></tr>
<tr><td colspan="3">Segmentation quality score</td><td>8.4.3.2</td><td>1 Byte</td><td>0-100, 254, or 255</td><td>254 – Quality not reported
255 – Quality computation failed</td></tr>
<tr><td colspan="3">Finger image quality algorithm and

Owner ID</td><td>8.4.3.3</td><td>4 Bytes</td><td>0000_{Hex} to $FFFF_{Hex}$
0000_{Hex} to $FFFF_{Hex}$</td><td>Quality algorithm vendor ID IBIA Assigned;
Owner Assigned (Optional IBIA Registered)</td></tr>
<tr><td colspan="3">Number of segments</td><td>8.4.3.4</td><td>1 Byte</td><td>0,1,2,3,4,255</td><td></td></tr>
<tr><td rowspan="6">Finger Segment Data
1 to 4</td><td colspan="2">Finger position</td><td>8.4.3.5.2</td><td>1 Byte</td><td>0 to 10</td><td>Refer to Table 6</td></tr>
<tr><td colspan="2">Finger quality</td><td>8.4.3.5.3</td><td>1 Byte</td><td>0-100,254, or 255</td><td>254 – Quality not reported
255 – Quality computation failed</td></tr>
<tr><td colspan="2">Number coordinates</td><td>8.4.3.5.4</td><td>1 Byte</td><td>2 to 99</td><td>There shall be 2 or more pairs of coordinates.</td></tr>
<tr><td rowspan="2">Coordinates (4 to 99)</td><td>X-coordinate</td><td>8.4.3.5.4.1</td><td>2 Bytes</td><td>0 to 2^{16}-1</td><td></td></tr>
<tr><td>Y- coordinate</td><td>8.4.3.5.4.2</td><td>2 Bytes</td><td>0 to 2^{16}-1</td><td></td></tr>
<tr><td colspan="2">Finger orientation</td><td>8.4.3.5.5</td><td>1 Byte</td><td>0 to 255</td><td></td></tr>
</table>

8.4.3.2 Segmentation quality score

This field shall be a measure of estimated correctness regarding the accuracy of the location of the segmented finger. It contains the binary representation of the integer segmentation quality score between 0 and 100 assigned to the image data by a quality algorithm. Higher values indicate better quality. An entry of “255” shall indicate a failed attempt to calculate a quality score. An entry of “254” shall indicate that no attempt to calculate a segmentation quality score was made.

8.4.3.3 Finger image quality algorithm and owner ID

Values of biometric sample quality shall be interpreted in view of the method used to assess the quality. Therefore, the quality assessment algorithm’s supplier (owner) and specific identity (ID) are contained in the next four bytes. The first two bytes shall contain the ID of the quality algorithm owner. This is the 16-bit format owner value assigned by the IBIA. The last two bytes shall contain a specific identifier for the quality assessment algorithm. This field contains the binary representation of the integer product code and should be within the range 1 to 65535. This value is assigned by the organization, and may be registered with the IBIA. Values of all 00_{Hex} for each of these bytes indicate that quality algorithm and vendor ID is unreported.

8.4.3.4 Number of segments

This 1-byte field shall contain the number of finger segments that follow. If an image is multi-finger impression then the value shall be 0. If a segmentation attempt failed then the value shall be 255.

8.4.3.5 Finger Segment Data

8.4.3.5.1 General

The following fields shall be present for each of the segmented finger images present. Each finger segment shall be defined by finger position, image quality, the number of points used to define the segment and the coordinates of each point. For rectangular bounding boxes, the number of coordinates points will be four, and the rectangle should be co-linear with the axis of the finger.

8.4.3.5.2 Finger position

The first information item for each finger segment is the finger number as chosen from Table 6.

8.4.3.5.3 Finger quality

The second byte shall be a quantitative expression of the predicted comparison performance of the biometric sample. This value is calculated by the algorithm identified in clause 8.4.3.3. This item contains the image quality score between 0 and 100 assigned to the image data by a quality algorithm. Higher values indicate better quality. A value of 255 shall indicate a failed attempt to calculate a quality score. A value of 254 shall indicate that no attempt to calculate a quality score was made.

8.4.3.5.4 Number of coordinate pairs

The third byte shall specify the number of points or vertexes used to enclose the segmented image. For a finger segment enclosed by an n-sided polygon, this byte shall contain a value between 4 and 99. The usual case is a value of four indicating a rotated rectangle.

The order of the vertices shall be in their consecutive order around the perimeter of the polygon, either clockwise or counterclockwise. No two vertices may occupy the same location. The polygon side defined by the last subfield and the first subfield shall complete the polygon. The polygon shall be a simple, plane figure with no sides crossing and no interior holes. Each vertex of the rectangle or polygon shall be represented by a pair of coordinates.

8.4.3.5.4.1 X-Coordinate

Two bytes shall be used to contain the horizontal pixel offset to the right relative to the origin positioned in the upper left corner of the image.

8.4.3.5.4.2 Y-Coordinate

Two bytes shall be used to contain the vertical pixel offset down relative to the origin positioned in the upper left corner of the image.

8.4.3.5.5 Finger orientation

This one byte field shall encode the angle between the longitudinal axis of the finger and the horizontal axis to the right. The integer value encoded shall be the physical estimate of the angle in degrees divided by 1.40625 = 360/256. The longitudinal axis of the finger is defined to be positive in the direction from the interphalangeal creases to the fingerprint tip. Figure 5 illustrates the measurement of the the finger orienttion for fingers 07 through 10.

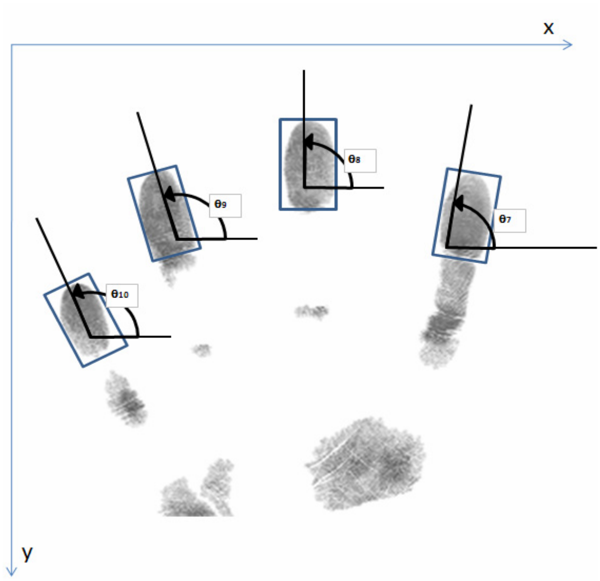


Figure 5 — Finger orientation for segmentation

8.4.4 Annotation data format

If the extended data type identification code is 0002_{Hex}, the extended data section contains annotation information. This format is provided to contain optional information about the fingerprints contained in a larger fingerprint image such as a 2 or 4 finger slap image. Table 13 summarizes the annotation data fields.

Table 13 — Annotation data

Field		Section	Size	Valid Values	Notes
Number of annotations		8.4.4.1	1 Bytes	1 to 4	
Annotation 1 or more	**Finger Position**	8.4.4.2	1 Byte	0 to 10; 13 to 15; 40 to 50 20 to 36	See Tables 6 to 8
	Annotation Code	8.4.4.3	1 Byte	1 or 2	01_{Hex} for amputated finger 02_{Hex} for unusable image

8.4.4.1 Number of annotations

This one-byte field shall contain the number of annotations that follow. Each annotation will consists of two information items.

8.4.4.2 Finger position

This byte shall contain the finger position number as chosen from Table 6 through Table 8.

8.4.4.3 Annotation code

This byte shall contain the code 01_{Hex} for an amputated finger and code 02_{Hex} for a bandaged or otherwise unable to print finger.

8.4.5 Comment data format

If the extended data type identification code is 0003_{Hex}, the extended data section contains ASCII text information associated with the captured image or subject supplying the image. The comment is inputted by the individual generating the fingerprint or palmprint record. A null terminator for the ASCII string is not necessary, as the length is provided.

9 Registered format type identifiers

The registration listed in Table 14 has been made with the CBEFF Registration Authority (see ISO/IEC 19785-2) to identify the finger image record format. The format owner is ISO/IEC JTC 1/SC 37 with the registered format owner identifier 257 (0101_{Hex}).

Table 14 — Format Type Identifiers

CBEFF BDB format Type identifier	Short name	Full object identifier
7 (0007_{Hex})	Finger-image	{iso registration-authority cbeff(19785)organization(0) 257 bdbs(0) finger-image (7)}

Annex A
(normative)

Conformance test methodology

A.1 Overview

This part of ISO/IEC 19794 specifies a biometric data interchange format for storing, recording, and transmitting one or more finger and/or palm representations. Each representation is accompanied by modality-specific metadata contained in a header record. This annex establishes tests for checking the correctness of the record.

The objective of this part of ISO/IEC 19794 cannot be completely achieved until biometric products can be tested to determine whether they conform to those specifications. Conforming implementations are a necessary prerequisite for achieving interoperability among implementations; therefore there is a need for a standardised conformance testing methodology, test assertions, and test procedures as applicable to specific modalities addressed by each part of ISO/IEC 19794. The test assertions will cover as much as practical of the ISO/IEC 19794 requirements (covering the most critical features), so that the conformity results produced by the test suites will reflect the real degree of conformity of the implementations to ISO/IEC 19794 data interchange format records. This is the motivation for the development of this conformance testing methodology.

This normative annex is intended to specify elements of conformance testing methodology, test assertions, and test procedures as applicable to this part of ISO/IEC 19794. For this edition of this part of ISO/IEC 19794, the content of this annex will be available as a separate document (Amendment), to supplement this part of ISO/IEC 19794.

Annex B
(normative)

Capture device certifications

B.1 Image quality specification for AFIS systems

B.1.1 General

These specifications apply to: (1) systems that scan and capture fingerprints[3] in digital, softcopy form, including hardcopy scanners such as card scanners, and live scan devices, altogether called “fingerprint scanners”; and (2) systems utilizing a printer to print digital fingerprint images to hardcopy called “fingerprint printers.” These specifications provide criteria for ensuring the image quality of fingerprint scanners and printers that input fingerprint images to, or generate fingerprint images from within, an Automated Fingerprint Identification System (AFIS).

Digital softcopy images obtained from fingerprint scanners shall have sufficient quality to allow the following functions to be performed: (l) conclusive fingerprint comparisons (identification or non-identification decision), (2) fingerprint classification, (3) automatic feature detection, and (4) overall AFIS search reliability. The fingerprint comparison process requires a high-fidelity image. Finer detail, such as pores and incipient ridges, are needed because they can play an important role in the comparison.

The fingerprint examiners in AFIS environment will depend upon softcopy-displayed images of scanned fingerprints to make comparisons, but will also need to accept and utilize hardcopy images in certain instances. For example, some contributors may print cards from live scan or card scan systems for submission to an AFIS. These hardcopy prints will be obtained from printers that include printing algorithms optimized for fingerprints. The printer’s principal function is to produce life-size prints of digital fingerprints that provide sufficient print quality to support fingerprint comparisons, *i.e.*, support identification or non-identification decisions.

The image quality requirements for fingerprint scanners are covered in Clauses B.1.2 and B.1.3. The compliance test procedures for these requirements are out of scope of this Annex. An example for a test specification that allows testing of conformance with this image quality specification is available [8].

B.1.2 Fingerprint scanner

The fingerprint scanner shall be capable of producing images that exhibit good geometric fidelity, sharpness, detail rendition, gray-level uniformity, and gray-scale dynamic range, with low noise characteristics. The images shall be true representations of the input fingerprints without creating any significant artifacts, anomalies, false detail, or cosmetic image restoration effects.

The scanner’s final output spatial sampling rate in both sensor detector row and column directions shall be in the range: (R–0,01R) to (R+0,01R) and shall be gray-level quantized to eight bits per pixel (256 gray-levels). The magnitude of “R” is either 500 pixels per inch (ppi) or 1000 ppi; a scanner may be certified at either one or both of these spatial sampling rate levels. The scanner’s true optical spatial sampling rate shall be greater than or equal to R.

A scanner intended to scan standard 8,0 by 8,0 inch tenprint cards, shall be capable of capturing an area of at least 5,0 by 8,0 inches, which captures all 14 print blocks, either each print block as a separate image or all print blocks together as a single image. In terms of individual print blocks, Table B.1 gives the preferred capture sizes applicable to both card scan and live scan systems, with the exception that, when scanning fingerprint cards, the card form dimensions take precedence.

3 The term “fingerprint” in this appendix may also include palmprint, whole hand print, or a print from other parts of the human body.

Table B.1 — Preferred capture sizes

	Preferred Width		Preferred Height	
	(in)	(mm)	(in)	(mm)
roll finger	1,6*	40,6	1,5	38,1
plain thumb	1,0	25,4	2,0	50,8
plain 4-fingers (sequence check)	3,2	81,3	2,0	50,8
plain 4-fingers (identification flat)	3,2	81,3	3,0	76,2
full palm	5,5	139,7	8,0	203,2
half palm	5,5	139,7	5,5	139,7
writer's palm	1,75	44,5	5,0	127,0

* Live scanner shall be capable of capturing at least 80% of full roll arc length, where full roll arc length is defined as arc length from nail edge to nail edge.

B.1.2.1 Linearity

B.1.2.1.1 Requirement

When measuring a stepped series of uniform target reflectance patches (*e.g.*, step tablet) that substantially cover the scanner's gray range, the average value of each patch shall be within 7,65 gray-levels of a linear, least squares regression line fitted between target reflectance patch values (independent variable) and scanner output gray-levels (dependent variable).

B.1.2.1.2 Background

All targets used in this image quality specification compliance verification are expected to be scanned with the scanner operating in a linear input/output mode. Linearity enables valid comparisons of test measurements with requirements, *e.g.*, a system's spatial frequency response in terms of Modulation Transfer Function is, strictly speaking, a linear systems concept. Linearity also facilitates comparisons between different scanners through the "common ground" concept. In atypical cases, a small amount of smooth, monotonic nonlinearity may be acceptable for the test target scans, *i.e.*, when it is substantially impractical and unrepresentative of operational use, to force linearity on the scanner under test (*e.g.*, some live scan devices). Linearity is not a requirement for the operational or test fingerprint scans, which allows for processing flexibility to overcome inadequate tonal characteristics of fingerprint samples.

B.1.2.2 Geometric accuracy

B.1.2.2.1 Requirement (across-bar)

When scanning a multiple, parallel bar target, in both vertical bar and horizontal bar orientations, the absolute value of the difference between the actual distance across parallel target bars and the corresponding distance measured in the image shall not exceed the following values for at least 99,0 percent of the tested cases in each print block measurement area and in each of the two orthogonal directions.

For 500-ppi scanner:

$D \leq 0{,}0007$, for $0{,}00 < X \leq 0{,}07$

$D \leq 0{,}01X$, for $0{,}07 \leq X \leq 1{,}50$

for 1000-ppi scanner:

$D \leq 0{,}0005$, for $0{,}00 < X \leq 0{,}07$

$D \leq 0{,}0071X$, for $0{,}07 \leq X \leq 1{,}5$

where:

D = |Y-X|

X = actual target distance

Y = measured image distance

D, X, Y are in inches.

B.1.2.2.2 Requirement (along-bar)

When scanning a multiple, parallel bar target, in both vertical bar and horizontal bar orientations, the maximum difference in the horizontal or vertical direction, respectively, between the locations of any two points within a 1,5-inch segment of a given bar image shall not exceed 0,016 inches for at least 99,0 percent of the tested cases in each print block measurement area and in each of the two orthogonal directions.

B.1.2.2.3 Background

The phrase: *multiple, parallel bar target* refers to a Ronchi target, which consists of an equal-width bar and space square wave pattern at 1,0 cy/mm, with high contrast ratio and fine edge definition. This target is also used to verify compliance with the scanner spatial sampling rate requirement given in clause B.1.2.

Across-bar geometric accuracy is measured across the imaged Ronchi target bars that substantially cover the total image capture area. The 500-ppi requirement corresponds to a positional accuracy of ± 1,0 percent for distances between 0,07 and 1,5 inches and a constant ± 0,0007 inches (1/3 pixel) for distances less than or equal to 0,07 inches. The 1000-ppi requirement corresponds to a positional accuracy of ± 0,71 percent for distances between 0,07 and 1,5 inches and a constant ± 0,0005 inches (1/2 pixel) for distances less than or equal to 0,07 inches.

This measurement procedure is also used to verify the ppi spatial sampling rate requirement given in clause B.1.2.3.

Along-bar geometric accuracy is measured along the length of an individual Ronchi target bar in the image. For a given horizontal bar, for example, the maximum difference between bar center locations (in vertical direction), determined from bar locations measured at multiple points along a 1,5” bar segment length, is compared to the maximum allowable difference requirement (analogously for vertical bar). This requirement is to ensure that pincushion or barrel distortion over the primary area of interest, *i.e.*, a single fingerprint, is not too large.

B.1.2.3 Spatial frequency response

B.1.2.3.1 Requirements

The spatial frequency response shall be measured using a continuous tone sine wave target denoted as Modulation Transfer Function (MTF) measurement unless the scanner cannot obtain adequate tonal response from this target, in which case a bi-tonal bar target shall be used to measure the spatial frequency response, denoted as Contrast Transfer Function (CTF) measurement. When measuring the sine wave MTF, it shall meet or exceed the minimum modulation values given in Table B.2 in both the detector row and detector column directions and over any region of the scanner’s field of view. When measuring the bar CTF, it shall meet or exceed the minimum modulation values defined by equation 2-1 or equation 2-2 (whichever applies) in both the detector row and detector column directions and over any region of the scanner’s field of view. CTF values computed from equations B.1 and B.2 for nominal test frequencies are given in Table B.3.

None of the MTF or CTF modulation values measured at specification spatial frequencies shall exceed 1,05.

The output sine wave image or bar target image shall not exhibit any significant amount of aliasing.

Table B.2 — MTF Requirement using sine wave target

Frequency (cy/mm)	Minimum Modulation for 500 ppi Scanner	Minimum Modulationfor 1000 ppi Scanner	Maximum Modulation
1	0,905	0,925	1,05 at all frequencies
2	0,797	0,856	
3	0,694	0,791	
4	0,598	0,732	
5	0,513	0,677	
6	0,437	0,626	
7	0,371	0,579	
8	0,312	0,536	
9	0,255	0,495	
10	0,200	0,458	
12		0,392	
14		0,336	
16		0,287	
18		0,246	
20		0,210	

Note: Testing at 7 and 9 cy/mm is not a requirement if these frequency patterns are absent from the sine wave target.

Table B.3 — CTF Requirement using bar target (nominal test frequencies)

Frequency (cy/mm)	Minimum modulation for 500 ppi scanner	Minimum modulation for 1000 ppi scanner	Maximum modulation
1,0	0,948	0,957	1,05 at all frequencies
2,0	0,869	0,904	
3,0	0,791	0,854	
4,0	0,713	0,805	
5,0	0,636	0,760	
6,0	0,559	0,716	
7,0	0,483	0,675	
8,0	0,408	0,636	
9,0	0,333	0,598	
10,0	0,259	0,563	
12,0		0,497	
14,0		0,437	
16,0		0,382	
18,0		0,332	
20,0		0,284	

Note: Testing at or near 7 and 9 cy/mm is a requirement when using a bar target.

It is not required that the bar target contain the exact frequencies listed in Table B.3; however, the target does need to cover the listed frequency range and contain bar patterns close to each of the listed frequencies. The following equations are used to obtain the specification CTF modulation values when using bar targets that contain frequencies not listed in Table B.3.

500-ppi scanner, for f = 1,0 to 10,0 cy/mm:

$$CTF = 3{,}04105E\text{-}04 * f^2 - 7{,}99095E\text{-}02 * f + 1{,}02774 \qquad \text{(eq.B.1)}$$

1000-ppi scanner, for f = 1,0 to 20,0 cy/mm:

$$CTF = -1{,}85487E\text{-}05 * f^3 + 1{,}41666E\text{-}03 * f^2 - 5{,}73701E\text{-}02 * f + 1{,}01341 \qquad \text{(eq.B.2)}$$

B.1.2.3.2 Background

For MTF assessment, the single, representative sine wave modulation in each imaged sine wave frequency pattern is determined from the sample modulation values collected from within that pattern. The sample modulation values are computed from the maximum and minimum levels corresponding to the “peak” and adjacent “valley” in each sine wave period. For a sine wave image, these maximum and minimum levels represent the image gray-levels that have been locally averaged in a direction perpendicular to the sinusoidal variation and then mapped through a calibration curve into target reflectance space. Sample image modulation in target reflectance space is then defined as:

modulation = (maximum - minimum) / (maximum + minimum)

The calibration curve is the curve of best fit between the image gray-levels of the density patches in the sine wave target and the corresponding target reflectance values. [It is assumed that sine wave target modulations and target density patch values are supplied by the target manufacturer.] The scanner MTF at each frequency is then defined as:

MTF = peak image modulation / target modulation

For CTF assessment, the modulations are determined directly in image space, normalized by the image modulation at zero frequency, instead of using a calibration curve. The scanner CTF at each frequency is then defined as:

CTF = peak image modulation / (zero frequency image modulation)

The bar target shall contain at least 10 parallel bars at each of the higher spatial frequencies (~50% Nyquist to Nyquist frequency), which helps to ensure capture of optimum scanner – target phasing and aids investigation of potential aliasing. The bar target shall also contain a very low frequency component, *i.e.*, a large square, bar, or series of bars whose effective frequency is less than 2,5 percent of the scanner’s final output spatial sampling rate. This low frequency component is used in normalizing the CTF; it shall have the same density (on the target) as the higher frequency target bars.

The upper limit of 1,05 modulation is to discourage image processing that produces excessive edge sharpening, which can add false detail to an image.

Aliasing on sine wave images or bar images may be investigated by quantitative analysis and from visual observation of the softcopy-displayed image.

B.1.2.4 Signal-to-noise ratio

B.1.2.4.1 Requirement

The white signal-to-noise ratio and black signal-to-noise ratio shall each be greater than or equal to 125,0 in at least 97,0 percent of respective cases within each print block measurement area.

B.1.2.4.2 Background

The signal is defined as the difference between the average output gray-levels obtained from scans of a uniform low reflectance and a uniform high reflectance target, measuring the average values over independent 0,25 by 0,25 inch areas within each print block area. The noise is defined as the standard deviation of the gray-levels in each of these quarter-inch measurement areas. Therefore, for each high reflectance, low reflectance image pair there are two SNR values, one using the high reflectance standard deviation and one using the low reflectance standard deviation. To obtain a true measure of the standard deviation, the scanner is set up such that the white average gray-level is several gray-levels below the system’s highest obtainable gray-level and the black average gray-level is several gray-levels above the system’s lowest obtainable gray-level.

B.1.2.5 Gray-level uniformity

B.1.2.5.1 Requirement – adjacent row, column uniformity

At least 99,0 percent of the average gray-levels between every two adjacent quarter-inch-long rows and 99,0 percent between every two adjacent quarter-inch-long columns within each imaged print block area shall not differ by more than 1,0 gray-levels when scanning a uniform low-reflectance target and shall not differ by more than 2,0 gray-levels when scanning a uniform high-reflectance target.

B.1.2.5.2 Requirement – pixel-to-pixel uniformity

For at least 99,9 percent of all pixels within every independent 0,25 by 0,25 inch area located within each imaged print block area, no individual pixel's gray-level shall vary from the average by more than 22,0 gray-levels when scanning a uniform high-reflectance target and shall not vary from the average by more than 8,0 gray-levels when scanning a uniform low-reflectance target.

B.1.2.5.3 Requirement – small area uniformity

For every two independent 0,25 by 0,25 inch areas located within each imaged print block area, the average gray-levels of the two areas shall not differ by more than 12,0 gray-levels when scanning a uniform high-reflectance target and shall not differ by more than 3,0 gray-levels when scanning a uniform low-reflectance target.

B.1.2.5.4 Background

Measurements are made over multiple, independent test areas on a print block-by-print block basis. (For a live scanner, the entire capture area is normally considered a single print block area). To obtain a true measure of the standard deviation, the scanner is set up such that the white average gray-level is several gray-levels below the system's highest obtainable gray-level and the black average gray-level is several gray-levels above the system's lowest obtainable gray-level.

B.1.2.6 Fingerprint image quality

The scanner shall provide high quality fingerprint images; the quality will be assessed with respect to the following requirements.

B.1.2.6.1 Requirement – Fingerprint gray range

At least 80,0 percent of the captured individual fingerprint images shall have a gray-scale dynamic range of at least 200 gray-levels, and at least 99,0 percent shall have a dynamic range of at least 128 gray-levels.

B.1.2.6.2 Background

Card and live scan systems at a booking station have some control over dynamic range on a subject-by-subject or card-by-card basis, *e.g.*, by rolling an inked finger properly or by adjusting gain on a livescanner. However, with central site or file conversion systems where a variety of card types and image qualities are encountered in rapid succession, automated adaptive processing may be necessary. The eight-bits-per-pixel quantization of the gray-scale values for very low contrast fingerprints needs to more optimally represent the reduced gray-scale range of such fingerprints, but without significant saturation. The intent is to avoid excessively low contrast images without adding false detail.

Dynamic range is computed in terms of number of gray-levels present that have signal content, measuring within the fingerprint area and substantially excluding white background and card format lines, boxes, and text.

For card scanners, compliance with these dynamic range requirements shall be verified using a statistically stratified sample set of fingerprint cards. The test fingerprint card set may include cards with difficult-to-handle properties, *e.g.*, tears, holes, staples, glued-on photos, or lamination, for testing card scanners that have automatic document feeder mechanisms. For live scanners, compliance will be verified with sets of livescans produced by the vendor.

B.1.2.6.3 Requirement – Fingerprint artifacts and anomalies

Artifacts or anomalies detected on the fingerprint images that are due to the scanner or image processing shall not significantly adversely impact support to the functions of conclusive fingerprint comparisons (identification or non-identification decision), fingerprint classification, automatic feature detection, or overall AFIS search reliability.

B.1.2.6.4 Background

The fingerprint images will be examined to determine the presence of artifacts or anomalies that are due to the scanner or image processing; assessment may include measurements to quantify their degree of severity and significance. Image artifacts or anomalies such as the following non-inclusive list may be investigated.

- jitter noise effects
- sharp truncations in average gray-level between adjacent print blocks
- gaps in the gray-level histograms, *i.e.*, zero pixels in intermediate gray-levels, or clipping to less than 256 possible gray-levels
- imaging detector butt joints
- noise streaks
- card bleed-through
- gray-level saturation

B.1.2.6.5 Requirement – Fingerprint sharpness & detail rendition

The sharpness and detail rendition of the fingerprint images, due to the scanner or image processing, shall be high enough to support the fingerprint functions stated in Clause B.1.1, paragraph 2.

B.1.2.6.6 Background

Fingerprint sharpness and detail rendition that is due to the scanner or image processing may be investigated by employing suitable, objective image quality metrics, as well as by visual observation of the softcopy-displayed image.

B.1.3 Identification flats

Traditional fingerprint sets contain both rolled and plain fingerprint images. The rolled impressions support the search processing and identification functions and the plain impressions are used primarily for sequence verification. Fingerprinting systems designed for "Identification Flats" civilian background checks capture a single set of plain impressions. This single set of plain impressions shall support finger sequence verification, search processing, and identification.

Image quality has historically been a challenge for civil background checks. Some programs require a large number of relatively low-volume capture sites, which makes training difficult. A key goal for identification flats scanners is to reduce the need for training so that inexperienced users consistently capture quality fingerprint images.

The identification flats scanner shall meet all of the requirements stated in Clause B.1.2 of this annex as well as the following requirements.

B.1.3.1 Requirement – Capture protocol

The system shall provide a simple capture protocol.

B.1.3.2 Background

A simple capture protocol supports the inexperienced user's ability to more consistently capture high quality fingerprints. Identification flats collection systems will be evaluated for their ability to produce a very small rate of failure to enroll in an operational setting. Systems with a minimum capture area of 3,2 inches (width) by 3,0 inches (height) that can capture four fingers simultaneously in an upright position will be considered in compliance with the simple capture protocol requirement. Other capture approaches will require specific testing and documentation.

B.1.3.3 Requirement – Verifiable finger sequence data

The method of capturing the fingers shall result in very low probability of error in the finger numbers.

B.1.3.4 Background

The fingerprinting system's capture protocol will be evaluated for its ability to capture verifiable finger sequence data. Systems with a minimum capture area of 3,2 inches (width) by 3,0 inches (height) that capture four fingers simultaneously in an upright position will be considered in compliance with the finger sequence requirements. Other capture approaches will require specific testing and documentation.

B.2 Image quality specification for personal verification

B.2.1 General

These specifications apply to fingerprint capture devices which scan and capture at least a single fingerprint in digital, softcopy form. These specifications provide criteria for insuring that the image quality of such devices is sufficient for the intended applications; a primary application is to support subject authentication via one-to-one fingerprint comparison.

The fingerprint capture device shall be capable of producing images which exhibit good geometric fidelity, sharpness, detail rendition, gray-level uniformity, and gray-level dynamic range, with low noise characteristics. The images shall be true representations of the input fingerprints, without creating any significant artifacts, anomalies, false detail, or cosmetic image restoration effects. The fingerprint capture device is expected to generate good quality finger images for a very high percentage of the user population, across the full range of environmental variations seen in the intended applications.

B.2.2 Requirements

The compliance test procedures are out of scope of this Annex. An example for a test specification that allows testing of conformance with this image quality specification is available [8].

Verification of compliance of the fingerprint capture device with the requirements shall primarily be performed by the *Test Method*, i.e., verification through systematic exercising of the item with sufficient instrumentation to show compliance with the specified quantitative criteria.

The device shall be tested to meet the requirements in its normal-operating-mode, with the following possible exceptions:

1) If the device has a strong anti-spoofing feature, of a type whereby only live fingerprints will produce an image, then this feature needs to be switched-off or bypassed in the target test mode of operation.

2) If the device's normal output is not a monochrome gray scale image, e.g., it is a binary image, minutia feature set, color image, etc., then the monochrome gray scale image needs to be accessed and output in the test mode of operation.

3) Other normal-operating-mode features of the device similar/comparable/analogous to (1) and (2) may need to be disengaged.

Table B.4 gives some of the basic requirements for the single finger capture device.

Table B.4 — Basic requirements

Parameter	Requirement
Capture Size	≥ 12,8 mm wide by ≥ 16,5 mm high
True Optical or Native Spatial sampling rate (Nyquist frequency)	≥ 500 ppi in sensor detector row and column directions
Spatial sampling rate Scale	490 ppi to 510 ppi in sensor detector row and column directions
Image Type	Capability to output monochrome image at 8 bits per pixel, 256 gray-levels (prior to any compression)

mm = millimeters
ppi = pixels per inch
≥ greater than or equal to

B.2.2.1 Geometric accuracy

B.2.2.1.1 Requirement #1 (across-bar)

A multiple, parallel bar target with a one cy/mm frequency is captured in vertical bar and horizontal bar orientations. The absolute value of the difference between the actual distance across parallel target bars, and the corresponding distance measured in the image, shall not exceed the following values, for at least 99% of the tested cases in each of the two orthogonal directions.

$D \leq 0,0013$, for $0,00 < X \leq 0,07$

$D \leq 0,018X$, for $0,07 \leq X \leq 1,50$

where:
D = |Y-X|
X = actual target distance
Y = measured image distance
D, X, Y are in inches

B.2.2.1.2 Requirement #2 (along-bar)

A multiple, parallel bar target with a one cy/mm frequency is captured in vertical bar and horizontal bar orientations. The maximum difference between the horizontal direction locations (for vertical bar) or vertical direction locations (for horizontal bar), of any two points separated by up to 1,5 inches along a single bar's length, shall be less than 0,027 inches for at least 99% of the tested cases in the given direction.

Requirements #1 and #2 may be verified by the *Inspection Method* instead of the *Test Method*, if the fingerprint capture device has all of the following characteristics, and adequate documentation for these characteristics is supplied:

— Construction of a suitable 1 cy/mm Ronchi target that will produce measurable images with the capture device requires extraordinary effort and resources.

— The sensor is a two-dimensional staring array (area array) on a plane (not curved) surface.

— There is no movement of device components, nor purposeful movement of the finger, during finger image capture.

— There is no device hardware component (e.g., a lens or prism) between the finger and the sensor, with the possible exception of a membrane on the sensor surface which, if present, does not alter the geometry of the imaged finger.

— Any signal processing applied to the captured finger image does not alter the geometry of the captured finger image.

B.2.2.1.3 Background

The phrase: *multiple, parallel bar target* refers to a Ronchi target, which consists of an equal width bar and space square wave pattern at 1,0 cy/mm, with high contrast ratio and fine edge definition.

Across-bar geometric accuracy is measured across the imaged Ronchi target bars, which cover the total image capture area. The requirement corresponds to a positional accuracy of ± 1,8% for distances between 0,07 and 1,5 inches, and a constant ± 0,0013 inches (2/3 pixel) for distances less than or equal to 0,07 inches. These across-bar measurements are also used to verify compliance with the device's spatial sampling rate scale tolerance requirement given in Table B.4.

Along-bar geometric accuracy is measured along the length of an individual Ronchi bar in the image. For a given horizontal bar, for example, the maximum difference between bar center locations (in vertical direction), determined from bar locations measured at multiple points along bar's length, is compared to the maximum allowable difference requirement (analogously for vertical bar). This requirement is to ensure that pincushion, barrel, or other types of distortion are not too large, over the area of a single fingerprint.

B.2.2.2 Spatial frequency response (SFR)

B.2.2.2.1 Requirements

The spatial frequency response shall normally be measured by either using a bi-tonal, high contrast bar target, which results in the device's Contrast Transfer Function (CTF), or by using a continuous-tone sine wave target, which results in the device's Modulation Transfer Function (MTF). If the device cannot use a bar target or sine wave target, i.e., a useable/measurable image cannot be produced with one of these targets, then an edge target can be used to measure the MTF[4].

The CTF or MTF shall meet or exceed the minimum modulation values defined in equation 1 (for CTF) or equation 2 (for MTF), over the frequency range of 1,0 to 10,0 cy/mm, in both the detector row and detector column directions, and over any region of the total capture area. Table B.5 gives the minimum CTF and MTF modulation values at nominal test frequencies. None of the CTF or MTF modulation values in the 1,0 to 10,0 cy/mm range shall exceed 1,12, and the target image shall not exhibit any significant amount of aliasing in that range.

Equation 1:

$$CTF = -5,71711E-05 * f^4 + 1,43781E-03 * f^3 - 8,94631E-03 * f^2 - 8,05399E-02 * f + 1,00838$$

Equation 2:

$$MTF = -2,80874E-04 * f^3 + 1,06255E-02 * f^2 - 1,67473E-01 * f + 1,02829$$

(equations valid for f = 1,0 to f = 10,0 cy/mm)

[4] If it is conclusively shown that neither a sine wave target, nor bar target, nor edge target can be used in a particular device, other methods for SFR measurement may be considered.

Table B.5 — CTF and MTF Requirements at nominal test frequencies

Frequency (f) in cy/mm at object plane	Minimum CTF Modulation when using Bar Target	Minimum MTF Modulation when using Sine Wave or Edge Target
1,0	0,920	0,871
2,0	0,822	0,734
3.0	0,720	0,614
4,0	0,620	0,510
5,0	0,526	0,421
6,0	0,440	0,345
7,0	0,362	0,280
8,0	0,293	0,225
9,0	0,232	0,177
10,0	0,174	0,135

B.2.2.2.2 Background

The 1,12 upper limit for modulation is to discourage image processing that produces excessive edge sharpening, which can add false detail to an image and/or excessive noise.

Aliasing can be investigated quantitatively (e.g., Fourier analysis) and, for sine wave or bar images, from visual observation of the softcopy-displayed images. It is recognized and accepted that some amount of aliasing-due-to-decimation is often unavoidable at the higher frequencies, but aliasing-due-to-upscaling is not acceptable at any frequency within the required Nyquist limit.

The target can be fabricated of any material and on any substrate suitable for measurement with the given device, working in reflective, transmissive, or other signal transfer mode, and in either two-dimensions or three-dimensions.

If the relation between output gray-level and input signal level is nonlinear, i.e., the device's input/output response is nonlinear, then this needs to be appropriately accounted for in the computations for MTF or CTF. [MTF and CTF are strictly defined only for a linear or linearized system.]

It is not required that the CTF or MTF be obtained at the exact frequencies listed in Table B.5; however, the CTF or MTF does need to cover the listed frequency range, and contain frequencies close to each of the listed frequencies.

Sine Wave Target - Commercially manufactured sine wave targets commonly contain a calibrated step tablet for measurement of the device's input/output response, and the target sine wave modulation values are also supplied, which are used to normalize the device output modulation values to arrive at the device MTF.

Bar Target - The bar target shall contain an adequate number of parallel bars at each spatial frequency, i.e., enough bars to help ensure capture of optimum phasing between the target and the device's sensor, and to aid investigation of potential aliasing. The bar target shall also contain a very low frequency component (less than 0,3 cy/mm), such as a single large bar, with the same density as the other bars (used for normalization).

If the device has a nonlinear response then a procedure analogous to that used for sine wave processing will have to be used to establish the effective bar image modulation values in target space.

The spatial frequency response of the bar target itself may not be known. In such a case, the device output bar modulation values (in image space or, if nonlinear response, in target space) are normalized by the near-zero frequency bar output modulation value, resulting in an acceptable measure of the device CTF.

Edge Target - The computation of MTF from an imaged edge target follows the relevant ISO standard [11]. The target edge is oriented at an angle of 5,2 degrees, alternately with respect to the sensor row and column directions. If the device has a nonlinear response then the nonlinearity needs to be measured and taken into account in the computations. The computed output modulation values are normalized to 1,0 at zero frequency (by dividing by the area of the line spread function), resulting in an acceptable measure of the device MTF. If the spatial frequency response of the target edge is known, then a further division by that response function is performed to obtain a more exact measure of the device MTF. The edge target shall contain at least two fiducial marks from which the image scale in the across-the-edge direction can be measured, in pixels per inch.

B.2.2.3 Gray-level uniformity

B.2.2.3.1 Requirement #1 - adjacent row, column uniformity

At least 99% of the average gray-levels between every two adjacent quarter-inch long rows and 99% between every two adjacent quarter-inch long columns, within the capture area, shall not differ by more than 1,5 gray-levels when scanning a uniform dark gray target, and shall not differ by more than 3,0 gray-levels when scanning a uniform light gray target.

B.2.2.3.2 Requirement #2 - pixel to pixel uniformity

For at least 99,0% of all pixels within every independent 0,25 by 0,25 inch area located within the capture area, no individual pixel's gray-level shall vary from the average by more than 8,0 gray-levels when scanning a uniform dark gray target, and no individual pixel's gray-level shall vary from the average by more than 22,0 gray-levels when scanning a uniform light gray target.

B.2.2.3.3 Requirement #3- small area uniformity

For every two independent 0,25 by 0,25 inch areas located within the capture area, the average gray-levels of the two areas shall not differ by more than 3,0 gray-levels when scanning a uniform dark gray target, and shall not differ by more than 12,0 gray-levels when scanning a uniform light gray target.

B.2.2.3.4 Requirement #4 - Noise

The noise level, measured as the standard deviation of gray-levels, shall be less than 3,5 in every independent 0,25 by 0,25 inch area located within the capture area, when scanning a uniform dark gray target and a uniform light gray target.

B.2.2.3.5 Background

Any suitable uniform light gray target and dark gray target may be used for measuring requirements #1 to #4, including a pseudo-target. [The pseudo-target concept images the blank capture area with, for example, the exposure time turned up or down, producing a uniform light gray or dark gray image, respectively.] Each target needs to cover the entire capture area.

The device is set up such that the light average gray-level is at least 4 gray-levels below the device's highest obtainable gray-level when capturing fingerprints, and the dark average gray level is at least 4 gray-levels above the device's lowest obtainable gray-level when capturing fingerprints. This avoids possible saturation levels and levels that are outside the range obtained in actual fingerprint captures.

B.2.2.4 Fingerprint image quality

The fingerprint capture device shall provide fingerprint image quality which is high enough to support the intended applications; a primary application is to support subject authentication via one-to-one fingerprint comparison.

The image quality will be assessed with respect to the following requirements, by applying visual and quantitative measurements to test livescans captured on the given device. These test livescans shall consist of:

— a set of 20 fingers, nominally acquired from 10 different subjects and 2 fingers per subject (preferably left/right index finger) and,

— a set of 5 index finger repeat captures from the same hand of a single subject.

All of these test livescans shall be supplied for assessment in 8 bits per pixel, monochrome (grayscale), uncompressed format (and have never been lossy-compressed).

B.2.2.4.1 Requirement #1 - Fingerprint Gray Range

At least 80,0 % of the captured individual fingerprint images shall have a gray-scale dynamic range of at least 150 gray-levels.

B.2.2.4.2 Background

Dynamic range is computed in terms of number of gray-levels present that have signal content, measuring within the fingerprint area and substantially excluding non-uniform background areas.

B.2.2.4.3 Requirement #2 - Fingerprint Artifacts and Anomalies

Artifacts or anomalies detected on the fingerprint images, which are due to the device or image processing, shall not significantly adversely impact supporting the intended applications.

B.2.2.4.4 Background

The fingerprint images will be examined to determine the presence of artifacts or anomalies which are due to the device or image processing; assessment may include measurements to quantify their degree of severity and significance. Image artifacts or anomalies such as the following non-inclusive list may be investigated:

• jitter noise effects
• localized offsets of fingerprint segments
• sensor segmentation / butt joints
• noise streaks, erratic pixel response
• gray-level saturation
• poor reproduceability

B.2.2.4.5 Requirement #3 - Fingerprint Sharpness & Detail Rendition

The sharpness and detail rendition of the fingerprint images, due to the device or image processing, shall be high enough to support the intended applications.

B.2.2.4.6 Background:

Fingerprint sharpness and detail rendition, which is due to the device or image processing, may be investigated by employing suitable, objective image quality metrics, as well as by visual observation of the softcopy-displayed images.

B.3 Requirements and test procedures for optical fingerprint scanners

B.3.1 Introduction

This annex details requirements and testing procedures for high quality optical fingerprint scanners.

B.3.2 Testing prerequisites

B.3.2.1 Requirements on the testing laboratory

All measurements have to be performed within a completely darkened optical laboratory without the influence of external light sources. The insensitivity of the scanner to external stray light is not subject of the tests to be performed. For some of the measurements it is necessary to extract light which is emitted by the scanner via prisms; this strongly enhances the sensitivity of the scanner with respect to false light. An exception here is the recording of fingerprints to test the gray scale range. For this test the normal room illumination has to be switched on, to ensure normal environment conditions similar to the typical usage of the device. While carrying out the measurements it has to be ensured that the optical surface of the fingerprint recording area has to be cleaned. For performing the tests on the scanner the test lab uses the following test tools:

- suitable software for data evaluation (Clause B.3.2.3)
- spreadsheet software
- suitable test targets (Clause B.3.2.4)

The personal of the test lab has to have fundamental knowledge on the test of optical systems/instruments, especially on the test of fingerprint scanners.

B.3.2.2 Requirements on the test object

For the test of the fingerprint scanner the manufacturer has to state the exact optical principle of the scanner, including necessary drawings (or pictures, tables). An image capture area of at least 16 mm x 20 mm is required.

The fingerprint scanner to be tested has to be fully functional. Adaptive or dynamic adjustment, calibration algorithms or spoof detection mechanisms inside the scanner or the scanner software (on the PC), which may include filters, compensation, optimization, dynamic contrast adjustment, have to be disabled during the test. For this purpose the manufacturer may have to provide an adapted software for the scanner in which such software parts/algorithms are deactivated. The software has to operate with constant parameter settings during the test. Only for testing the gray scale range of fingerprint images dynamic algorithms which will be used in customer applications are allowed.

B.3.2.3 Requirements on the evaluation software

The software to evaluate the fingerprint digital image data has to compute image quality based on the two-dimensional spatial frequency power spectrum of the fingerprint digital image. The power spectrum, which is the square of the magnitude of the image's Fourier transform, contains information on the sharpness, contrast, and detail rendition of the image. These are components of visual image quality. Within the software, the power spectrum is normalized by image contrast, average gray level (brightness), and image size; a visual response function filter is applied, and the pixels per inch (ppi) spatial sampling rate scale of the fingerprint image is taken into account. The fundamental output is a single-number image quality value which is the sum of the filtered, scaled, weighted power spectrum values. The power spectrum normalizations allow valid comparisons between disparate fingerprint images. The software has to work as described in the following list:

- The software shall have the digital fingerprint image as input.
- It shall define a square window width of about 60% of fingerprint image width.
- It shall locate the left / right and bottom / top edges of the fingerprint.

- It shall define a set of overlapping windows covering the entire fingerprint area.
- It shall exclude very dense and very low structure areas within the fingerprint from further evaluation.
- It shall compute the 2-D power spectrum of each window and $|FFT|^2$.
- It shall be normalized by total energy and window size.
- It shall apply a Human Visual System (HVS) filter (inclusion of such a filter makes the final quality values more closely correspond to human observer assessments of relative quality).
- It shall use an initial image quality value per window, i.e. the 2-D normalized, filtered power spectrum values at non-zero frequencies are summed, resulting in a single quality number for the given sub image.
- It shall identify the window with the highest image quality.

It shall convert the image quality to the dc normalized image quality, that means it has to scale the fingerprint image to them range [0,100], where 0 is the worst quality, 100 is the best quality.

- The image quality overestimates dark areas within the fingerprint images and underestimates bright areas. This effect shall be compensated by multiplying the image quality value with the square of the average gray values.
- It shall check for special cases (very high contrast or very light, structured image) and adjust the image quality accordingly.
- It shall scale by ppi and normalize the image quality to the range [0,100].

B.3.2.4 Demands on the test targets

B.3.2.4.1 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the bright field

Test targets have to be used, which are closely related to the functional principle of the fingerprint scanner. During the tests with these targets no intervention in the optical beam path of the scanner shall be performed. The targets have to be placed directly on the optical recording surface of the scanner. The targets are made as specular reflecting, structured or unstructured mirrors. Light emerging from the optical recording surface of the scanner will not only be reflected from the front surface of the target, but also from the back side of the target. To avoid these parasite reflections, a prism has to be placed on top of the target, to couple out this light. For this purpose, an immersion liquid has to be inserted between scanner and target and also between target and prism; the refractive index of this liquid has to be close to those of optical glasses (optical recording surface of the scanner, target, prism). This liquid layer has to contain neither dust nor air bubbles. It is recommended to use an immersion liquid with a reflective index of n~1,5.

B.3.2.4.2 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the dark field

Test targets have to be used, which are closely related to the functional principle of the fingerprint scanner. During the tests with these targets no intervention in the optical beam path of the scanner shall be performed. The targets have to be placed directly on the optical recording surface of the scanner. For the optical coupling between scanner and target an immersion liquid has to be inserted; the refractive index of this liquid has to be identical with those of the optical recording surface of the scanner. This liquid layer has to contain neither dust nor air bubbles. It is recommended to use an immersion liquid with a reflective index of n~1,5.

The targets are made as diffusely reflecting areas. On these substrates defined gray levels (grayscales) can be generated by suitable exposure processes. The targets material is required to be liquid resistant. If the targets are laminated to protect them from liquid, care has to be taken that the lamination process does not change the optical properties of the targets.

B.3.3 Requirements and test procedures

B.3.3.1 Investigation of the grayscale linearity

B.3.3.1.1 Requirements

When measuring a stepped series of uniform target reflectance patches (“step tablet”) that substantially covers the scanner’s gray range, the average value of each patch shall be within 7,65 gray-levels of a linear, least squares regression line fitted between target reflectance patch values (independent variable) and scanner output gray-levels of 8 bit spatial sampling rate (dependent variable).

B.3.3.1.2 Background

All targets used within this test case are expected to be scanned with the scanner operating in a linear input/output mode. Linearity enables valid comparisons of test measurements with requirements. For fingerprint scans, linearity produces a pristine image in a common reference base. From this base, users can then apply linear/non-linear processing, as needed for specific purposes, with the benefit that they are always able to get back to the base image. However, in a typical case, linearity may be waived for test target scans; i.e., a small amount of smooth, monotonic nonlinearity may be acceptable when it is substantially impractical and unrepresentative of operational use to force linearity on the scanner under test. Such cases require the submission of documentation along with the waiver request.

It is recognized that the fingerprint on the scanner may have less than ideal characteristics, in terms of average reflectance, discontinuities in average reflectance, low contrast or background clutter. Such problems may sometimes be minimized by applying nonlinear gray-level processing to the scanner captured image. For these reasons, linearity is not a requirement for the operational or test fingerprint scans.

B.3.3.1.3 Used targets

B.3.3.1.3.1 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the bright field

For this test case targets with a metal coated surface may be used; within these targets different reflectivities are realized. Chromium or aluminium may be used; chromium can be very well deposited in different densities, but allows a maximum reflection of about 50%. Aluminium has a maximum reflectivities of about 85-92%, but it is difficult to depose it in different densities. As the reflectivities of the target surfaces cannot be correctly predicted, the reflectivities of all targets have to be measured accurately.

B.3.3.1.3.2 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the dark field

For this test case targets with diffusely reflecting surfaces with different blackened test fields are used. Such targets are commercially used for testing the modulation transfer function (MTF) of flat bed scanners. According to the size of the recording surface the target is cut into pieces with two or more test fields. By this way multiple test fields can be placed simultaneously on the recording surface.

B.3.3.1.4 Test procedure

B.3.3.1.4.1 Test step 1

A series of fields with different reflection values have to be placed one after another on the fingerprint scanner and an image of each target has to be recorded. At least nine targets with different reflection values, which substantially cover the dynamic range of the scanner, have to be recorded.

B.3.3.1.4.2 Test step 2

Adjacent the average gray value of each target image shall be determined with a suitable software. The reflectivity and the resulting gray value of each target shall be determined as pair of values.

B.3.3.1.4.3 Test step 3

For those pairs of values a linear regression shall be performed. For each average gray value the difference to the resulting regression line shall be determined.

B.3.3.1.5 Requirement compliance

None of the calculated differences in test step 3 is allowed to be larger than 7,65 gray values.

B.3.3.2 Investigation of the spatial sampling rate and geometrical accuracy

B.3.3.2.1 Requirements

Spatial sampling rate: The scanner's final output fingerprint image shall have a spatial sampling rate, in both sensor detector row and column directions, in the range: (R – 0,01R) to (R + 0,01R). The magnitude of R is either 500 ppi or 1000 ppi; a scanner may be certified at either one or both of these spatial sampling rate levels. The scanner's true optical spatial sampling rate shall be greater than or equal to R.

Across-Bar geometric accuracy: When scanning a 1,0 cy/mm, multiple parallel bar target, in both vertical bar and horizontal bar orientations, the absolute value of the difference (D), between the actual distance across parallel target bars (X), and the corresponding distance measured in the image (Y), shall not exceed the following values, for at least 99% of the tested cases in each print block measurement area and in each of the two directions

- for 500 ppi scanners: $D \leq 0{,}0007$, for $0{,}00 < X \leq 0{,}07$ and $D \leq 0{,}01X$, for $0{,}07 \leq X \leq 1{,}50$
- for 1000 ppi scanners: $D \leq 0{,}0005$, for $0{,}00 < X \leq 0{,}07$ and $D \leq 0{,}0071X$, for $0{,}07 \leq X \leq 1{,}50$

where $D = |Y\text{-}X|$, X = actual target distance, Y = measured image distance (D, X, Y are in inches)

Along-Bar geometric accuracy: When scanning a 1,0 cy/mm, multiple parallel bar target, in both vertical bar and horizontal bar orientations, the maximum difference in the horizontal or vertical direction, respectively, between the locations of any two points within a 1,5 inch segment of a given bar image, shall be less than 0,016 inches for at least 99% of the tested cases in each print block measurement area and in each of the two orthogonal directions.

B.3.3.2.2 Background

A multiple parallel bar target refers to a Ronchi target, which consists of an equal-width bar and space square wave pattern with high contrast ratio and sharp edge definition. For a 500 ppi system, the spatial sampling rate shall be between 495,0 and 505,0 ppi; for a 1000 ppi system, the spatial sampling rate shall be between 990,0 and 1010,0 ppi. The scanner's true optical spatial sampling rate may be greater than the required spatial sampling rate, in which case rescaling down to the required spatial sampling rate is performed for final output. However, the scanner's true optical spatial sampling rate cannot be less than the required spatial sampling rate; i.e. "up scaling", from less than the required ppi spatial sampling rate, to the required ppi spatial sampling rate, is not allowed. Across-bar geometric accuracy is measured across imaged 1,0 cy/mm Ronchi target bars that substantially cover the total image capture area. The 500ppi requirement corresponds to a positional accuracy of ± 1,0% for distances between 0,07 and 1,5 inches, and a constant ± 0,0007 inches (1/3 pixel) for distances less than or equal to 0,07 inches. The 1000ppi requirement corresponds to a positional accuracy of ± 0,71% for distances between 0,07 and 1,5 inches, and a constant ± 0,0005 inches (1/2 pixel) for distances less than or equal to 0,07 inches.

Along-bar geometric accuracy is measured along the length of imaged, 1,0 cy/mm Ronchi target bars that substantially cover the total image capture area. For a given horizontal bar, for example, the maximum difference between bar centre locations (in vertical direction), determined from bar locations measured at multiple points along a 1,5 inch bar segment length, is compared to the maximum allowable difference requirement (analogously for vertical bar). This requirement is to ensure that pincushion or barrel distortion over the primary area of interest; i.e., a single fingerprint is not too large.

B.3.3.2.3 Used targets

B.3.3.2.3.1 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the bright field

The target has to cover at least 70% of the recording surface of the fingerprint scanner. The test structure is a grating with a constant period length of 1mm. The target can consist of directly reflecting structures, such as chromium stripes on a glass substrate. The light passing the glass substrate has to be coupled out by a prism which has to be placed on top of the target.

Alternatively to this chromium coated glass target a plastic foil printed with black lines can be used. In this case no prism on top of the target is required. Reflexion of the light is performed on the back side of the foil. The black printed areas of the foil absorb and scatter the light, thus these areas appear dark in the image. The usage of this target material is recommended for larger fingerprint scanning surfaces.

B.3.3.2.3.2 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the dark field

The target has to cover at least 70% of the recording surface of the fingerprint scanner. The test structure is a grating with a constant period length of 1mm.

The target has to consist of diffuse bright reflecting material, on which dark structures are applied. These structures can be applied by a photographic process or by printing. Photographic or coated paper shall not be used as target material, because its optical properties can be influenced by wetting the material with immersion liquid. Thus, plastic material coated with photo emulsion as substrate is recommended; this material is insensitive against immersion liquid; the dark structures can be applied similar to the photographic process on paper.

B.3.3.2.4 Test procedure

B.3.3.2.4.1 Test step 1

The targets have to be placed with immersion liquid or similar on the recording surface of the fingerprint scanner. When using chromium coated glass targets the light passing the glass substrate has to be coupled out by a prism which has to be place on top of the target. When using black printed plastic foils as target this prism is not necessary. Each target has to be placed 4 times on the recording surface of the fingerprint scanner, two times with the lines in vertical direction (each time turned by 180°) and two times with the lines in horizontal direction (each time turned by 180°). By using this method, errors induced by the target and not by the fingerprint scanner can be detected.

After placing the target on the recording surface of the fingerprint scanner one has to ensure that the stripes of the target are parallel to the pixels of the scanner. To detect this, one has to look for aliasing effects at the edge of the stripes while looking at the recorded images on a high quality monitor.

B.3.3.2.4.2 Test step 2

The pixels coordinates of the edges of the stripe field in the recorded image are determined. These data and the picture dimensions are necessary for the evaluation by suitable software (see ‘Demand on the evaluation software’). This software determines within the specified measurement field the distance between neighbouring stripes, the average distance between six stripes and the coordinates of the central line of each stripe. As a unit, pixels shall be used.

B.3.3.2.4.3 Test step 3

Based on the results of test step 2 and the well known grating period of the test target (1 mm) the spatial sampling rate of the scanner at different positions within the image can be determined. This spatial sampling rate can be used to rescale the distance between the stripes from pixel to mm. Based on these values the difference between theoretical and measured distance between the stripes can be calculated for different measurement areas. From the position of the stripes and their lateral bend the scanner distortion can be measured.

B.3.3.2.5 Requirement compliance

The values listed under “Requirements” within this test case have to be completely met.

B.3.3.3 Investigation of the contrast transfer function

B.3.3.3.1 Requirements

The spatial frequency response shall be measured using a binary grid target (Ronchi-Grating), denoted as contrast transfer function (CTF) measurement. When measuring the bar CTF, it shall meet or exceed the minimum modulation values defined by equation [EQ 1] or equation [EQ 2], in both the detector row and detector column directions, and over any region of the scanner's field of view. CTF values computed from equations [EQ 1] and [EQ 2] for nominal test frequencies are given in Table B.6. None of the CTF modulation values measured at specification spatial frequencies shall exceed 1,05. The output bar target image shall not exhibit any significant amount of aliasing.

Table B.6 — Minimum and maximum modulation

Frequency [cy/mm]	Minimum Modulation for 500 ppi scanners	Minimum Modulation for 1000 ppi scanners	Maximum Modulation
1,0	0,948	0,957	1,05
2,0	0,869	0,904	1,05
3,0	0,791	0,854	1,05
4,0	0,713	0,805	1,05
5,0	0,636	0,760	1,05
6,0	0,559	0,716	1,05
7,0	0,483	0,675	1,05
8,0	0,408	0,636	1,05
9,0	0,333	0,598	1,05
10,0	0,259	0,563	1,05
12,0	---	0,497	1,05
14,0	---	0,437	1,05
16,0	---	0,382	1,05
18,0	---	0,332	1,05
20,0	---	0,284	1,05

It is not required that the bar target contain the exact frequencies listed in the previous table, however, the target does need to cover the listed frequency range and contain bar patterns close to each of the listed frequencies. The following equations are used to obtain the minimum acceptable CTF modulation values when using bar targets that contain frequencies not listed in the previous table.

- 500 ppi scanner, for f = 1,0 to 10,0 cy/mm: $CTF = 3{,}04105E\text{-}04 * f^2 – 7{,}99095E\text{-}02 * f + 1{,}02774$ [EQ 1]

- 1000 ppi scanner, for f = 1,0 to 20,0 cy/mm: $CTF = - 1{,}85487E\text{-}05*f^3 +1{,}41666E\text{-}03*f^2 – 5{,}73701E\text{-}02* f +1{,}01341$ [EQ 2]

For a given bar target, the specification frequencies include all of the bar frequencies which that target has in the range 1 to 10 cy/mm (500 ppi scanner) or 1 to 20 cy/mm (1000 ppi scanner).

B.3.3.3.2 Background

A multiple parallel bar target refers to a Ronchi target, which consists of an equal-width bar and space square wave pattern with high contrast ratio and sharp edge definition. These targets have to have all spatial frequencies in the range mentioned in the requirements section. All these gratings have to be place on one single target. Additionally, on this target there have to be large black and white structures to determine a CTF at a frequency of about 0 cy/mm. The spatial frequency of these structures has to be smaller than 3% of the Nyquist frequency. For all scanners these structures have to have a width of at least 1,7 mm. Each of the test field with the frequencies listed above have to have an adequate number and length of the gratings as listed in Table B.7:

Table B.7 — Dimensions of the target structures

Spatial Frequency R [mm^{-1}]	Min. number of Stripes	Width of the stripes [mm]	Min. length of the stripes [mm]	R/R Nyquist (at 500ppi)	R/R Nyquist (at 1000ppi)
0,3	1	>1,700	2,50	3%	1,5%
1	4	0,500	2,50	10%	5%
2	5	0,250	1,25	20%	10%
3	5	0,167	0,85	30%	15%
4	5	0,125	0,63	40%	20%
5	10	0,100	0,50	50%	25%
6	10	0,083	0,42	60%	30%
7	10	0,071	0,36	70%	35%
8	10	0,063	0,32	80%	40%
9	10	0,056	0,28	90%	45%
10	10	0,050	0,25	100%	50%
12	10	0,042	0,25	---	60%
14	10	0,036	0,25	---	70%
16	10	0,032	0,25	---	80%
18	10	0,028	0,25	--	90%
20	10	0,025	0,25	---	100%

B.3.3.3.3 Used targets

B.3.3.3.3.1 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the bright field

The target can consist of directly reflecting structures, such as chromium stripes on a glass substrate. The target has to be structured as mentioned in the section above. The light passing the glass substrate has to be coupled out by a prism which has to be placed on top of the target (see 'Demands on the test targets').

Alternatively to this chromium coated glass target a plastic foil printed with black lines can be used as target. In this case no prism on top of the target is required. Reflection of the light is performed on the back side of the foil. The black printed areas of the foil absorb and scatter the light, thus these areas appear dark in the image. The usage of this target material is recommended for larger fingerprint scanning surfaces.

When determining the CTF one has to consider that the target has a certain frequency response (mainly caused by the manufacturing process). Thus the CTF of all used targets has to be tested by a microscope before using them for this investigation.

If the target covers at least 25% of the recording surface of the fingerprint scanner, it has to be placed only once in the centre of the recording surface. Otherwise it has to be placed twice on the recording surface, left and right of the centre. Thus, the corresponding number of images has to be recorded.

B.3.3.3.3.2 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the dark field

The target has to consist of diffuse bright reflecting material, on which dark structures are applied. These structures can be applied by a photographic process or by printing. Photographic or coated paper shall not be used as target material, because its optical properties can be influenced by wetting the material with immersion liquid. Thus, plastic material coated with photo emulsion as substrate is recommended; this material is insensitive against immersion liquid; the dark structures can be applied similarly to the photographic process on paper.

When determining the CTF, one has to consider that the target has a certain frequency response (mainly caused by the manufacturing process). Thus the CTF of all used targets has to be investigated by a microscope before using them for this test.

If the target covers at least 25% of the recording surface of the fingerprint scanner, it has to be placed only once in the centre of the recording surface. Otherwise it has to be placed twice on the recording surface, left and right of the centre. Thus, the corresponding number of images has to be recorded.

B.3.3.3.4 Test procedure

B.3.3.3.4.1 Test step 1

The targets have to be placed on the recording surface (see 'Demands on the tast targets' section). The alignment of the targets with respect to the pixel rows of the image has to be better than 0,5°. From each target two images have to be recorded, one with the stripes aligned in vertical direction, a second with the stripes aligned in horizontal direction.

B.3.3.3.4.2 Test step 2

Adjacent within the recorded images the coordinates of the edges of a rectangular surrounding all gratings are determined. With these coordinates, the file size and the dimension of the test targets, the CTF of all single test gratings will be calculated.

B.3.3.3.4.3 Test step 3

The determined CTF values have to be corrected by using the real/measured modulation of the target (see 'Target' section). In addition the target modulation realizes no perfect “black” and “white”. Thus the modulation has to be corrected by using the “black” and “white” values determined from the large structures as mentioned in section “Background”; all CTF values have to be divided by this modulation.

B.3.3.3.5 Requirement compliance

The values listed under “Requirements” within this test case have to be completely met. The CTF values for horizontal and vertical direction have to correspond to these values. The acquired images are not allowed to show significant aliasing effects.

B.3.3.4 Investigation of the signal-to-noise ratio and the gray–level uniformity

B.3.3.4.1 Requirements

The white signal-to-noise ratio (SNR) and black SNR shall each be greater than or equal to 125,0, in at least 97% of respective cases, within each measurement area.

The gray level uniformity is defined for the three following cases:

- Adjacent row, column uniformity: At least 99% of the average gray-levels between every two adjacent quarter-inch long rows and 99% between every two adjacent quarter-inch long columns, within each imaged area, shall not differ by more than 1,0 gray-levels when scanning a uniform low reflectance target, and shall not differ by more than 2,0 gray-levels when scanning a uniform high reflectance target.

- Pixel to pixel uniformity: For at least 99,9% of all pixels within every independent 0,25 inch by 0,25 inch area located within each imaged area, no individual pixel's gray-level shall vary from the average by more than 22,0 gray-levels, when scanning a uniform high reflectance target, and shall not vary from the average by more than 8,0 gray-levels, when scanning a uniform low reflectance target.

- Small area uniformity: For every two independent 0,25 inch by 0,25 inch areas located within each imaged area, the average gray-levels of the two areas shall not differ by more than 12,0 graylevels when scanning a uniform high reflectance target, and shall not differ by more than 3,0 gray-levels when scanning a uniform low reflectance target.

B.3.3.4.2 Background

The signal is defined as the difference between the average output gray-levels obtained from scans of a uniform low reflectance and a uniform high reflectance target, measuring the average values for independent 0,25 inch * 0,25 inch areas within each scanned area. The noise is defined as the standard deviation of the gray-levels in each measurement area. Therefore, for each high reflectance, low reflectance image pair, there are two SNR values, one using the high reflectance standard deviation and one using the low reflectance standard deviation. The scanner shall be set up such that the average image gray-level of the high reflectance target is below 255 or high clipping level, whichever is lower, and the average image gray-level of the low reflectance target is above 0 or low clipping level, whichever is higher. Note that in this method of measuring SNR, no attempt is made to isolate different sources of noise or separately measure different types of noise; the computed noise represents all noise types and sources taken together. The gray level uniformity is calculated from the same images as described in “Requirements”.

B.3.3.4.3 Used targets

B.3.3.4.3.1 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the bright field

For the measurements of the signal-to-noise ratio and the gray–level uniformity the utilization of high reflecting targets, which are applied on the recording surface of the scanner, is precluded. For this test homogenous absorbing targets with a constant optical density have to be placed in the beam path of the scanner. The resulting image shall be an equable bright or dark image, whose average gray value has to be four gray values above the minimum gray value of the scanner or respectively four gray values below the maximum gray value of the scanner. If the targets are placed within the optical beam path of the scanner, they shall be realized as thin filters to avoid a beam displacement which would lead to inhomogenities and enhanced noise.

B.3.3.4.3.2 Test targets for optical fingerprint scanner working on the principle of frustrated total internal reflection in the dark field

The target has to consist of diffuse bright and dark reflecting material. The targets have to be homogeneous to fulfil together with the scanner the listed requirements. For the test e.g. the following Munsell test normal are recommended: N3 (dark, 7% reflection), N9 (bright, 79% reflection). When using the target its substrate can be wettened by the used immersion liquid. Its optical properties are normally not influenced by this, but the test can only be performed once with one target and has to be performed as fast as possible.

B.3.3.4.4 Test procedure

B.3.3.4.4.1 Test step 1

For optical fingerprint scanners working on the principle of disturbed total reflection in the bright field: The filters have to be inserted in the optical beam path of the scanner (opened housing of the scanner) or the exposure time of the scanner has to be accordingly adjusted. For each filter inserted in the beam path or each setting of the exposure time an image of the free image capture area has to be recorded, resulting at least in one bright and one dark image.

For optical fingerprint scanners working on the principle of disturbed total reflection in the dark field: The targets have to be placed with immersion liquid as interface medium on the recording surface. From each of the two target one images has to be recorded, resulting in one bright and one dark image.

B.3.3.4.4.2 Test step 2

For determining the SNR the acquired pictures is divided into test fields of the size 0,25 inch *0,25 inch and the mean gray value, the number of false pixels, and the standard deviation of the gray values of all rows and columns of this test field are determined. With these values the SNR and the gray-level uniformity are calculated. The SNR will be calculated for all test fields distributed all over the image. For each pixel the difference to the average gray value of the test field will be calculated. To determine the SNR in the bright and the dark field the quotient of these values with the standard deviation of the gray values of each test field in the bright and the dark field are calculated.

For determining the gray-level uniformity the acquired pictures is again divided into test fields of the size 0,25 inch * 0,25 inch and the mean gray value, the number of false pixels, and the standard deviation of the gray values of all rows and columns of this test field are determined.

B.3.3.4.5 Requirement compliance

The values listed under “Requirements” within this test case have to be completely fulfilled.

B.3.3.5 Investigation of the gray scale range of fingerprint images

B.3.3.5.1 Requirements

A fingerprint scanner operating at 500ppi or 1000ppi, has to perform the following sets of live scans:

For a standard roll and plain finger live scanner: capture a complete set of fingerprints from each of 10 subjects; i.e., 10 rolls (all 5 fingers from each hand), 2 plain thumb impressions, and 2 plain 4-finger impressions.

For a palm scanner component of a live scan system: capture left and right palms from each of 10 subjects.

For an identification flats live scanner: capture left and right 4-finger plain impressions and dual thumb plain impressions from each of 10 subjects.

Within the histogram of each image all gray values with at least 5 Pixels in this image are counted. The histogram has to show no break and no other artefact. At least 80% of the captured individual fingerprint images shall have a gray-scale dynamic range of at least 200 gray-levels, and at least 99% shall have a dynamic range of at least 128 gray-levels.

B.3.3.5.2 Background

This test shows the scanner performance in normal operation mode.

B.3.3.5.3 Used targets

No targets are used in this test case.

B.3.3.5.4 Test procedure

B.3.3.5.4.1 Test step 1

The test persons have to place their finger one after another on the image capture area of the fingerprint scanner. From each finger a single image is recorded. If the scanner can record four finger images, such an image of each hand is recorded.

B.3.3.5.4.2 Test step 2

The histograms of all images are evaluated according to the previously listed requirements.

B.3.3.5.5 Requirement compliance

The values listed under “Requirements” within this test case have to be completely met.

Annex C
(informative)

Finger image data record example

The fingerprint image in the illustration below will serve as example of the data encoding process and will be formatted according to this part of ISO/IEC 19794. Assume it originated from a left index finger and that the rolled image was captured using a live-scan device. Although the device technology is unknown the scan spatial sampling rate was 500 ppi using an 8-bit bit-depth. The image has pixel dimensions of 375x625 and will be formatted as uncompressed for the purpose of illustration. The device has one quality block and one certification block. The required fields for this example are illustrated in Table C.1 and Table C.2.

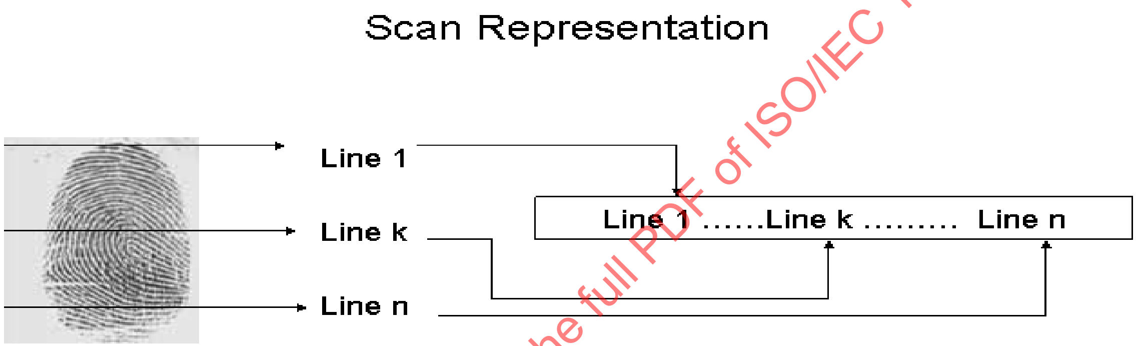


Table C.1 — General record header example

Field	Bytes	Value	Notes
Format identifier	4	46495200_{Hex}	“FIR” – Finger Image Record
Version number	4	30323000_{Hex}	“020”
Length of record	4	$000393C9_{Hex}$	One finger representation 16 length of general header +50 length of repr. header +234375 length of data = 234441 bytes
Number of representations	2	0001_{Hex}	Single capture of the finger image
Device certification block	1	01_{Hex}	Certification blocks are present
Number of fingers/palms	1	01_{Hex}	Left index finger only

Table C.2 — Finger image header record example

Field	Bytes	Values	Notes
Length of finger data block (bytes)	4	00 03 93 $B9_{Hex}$	Includes header, and largest image data block
Capture Date-time	9	07D5 0C 0F 11 23 13 0000_{Hex}	December 15,2005 at 17:35:19.000
Capture device technology identifier	1	00_{Hex}	Technology unknown or unspecified
Capture device vendor identifier	2	$ABCD_{Hex}$	Vendor IBIA ID
Capture device type identifier	2	1235_{Hex}	Vendor assigned ID
Number of quality blocks	1	01_{Hex}	One image quality block
Quality value	1	$3A_{Hex}$	Image quality of 58
Quality algorithm vendor ID	2	$ABCD_{Hex}$	Vendor IBIA ID
Quality algorithm ID	2	1234_{Hex}	Vendor assigned ID
Number certification blocks	1	01_{Hex}	One certification block
Certification authority identifier	2	$78AB_{Hex}$	IBIA ID
Certification identifier	1	01_{Hex}	Certification using Annex B.1
Finger/palm position	1	07_{Hex}	Left index finger
Representation number	1	00_{Hex}	First capture
Scale units	1	01_{Hex}	Pixels/inch
Scan spatial sampling rate (horiz)	2	$01F4_{Hex}$	500 pixels per inch
Scan spatial sampling rate (vert)	2	$01F4_{Hex}$	500 pixels/inch
Image spatial sampling rate (horiz)	2	$01F4_{Hex}$	500 pixels/inch
Image spatial sampling rate (vert)	2	$01F4_{Hex}$	500 pixels/inch
Bit-depth	1	08_{Hex}	256 gray levels
Image compression Algorithm	1	00_{Hex}	Uncompressed (no bit packing)
Impression type	1	01_{Hex}	Live-scan rolled
Horizontal line length	2	0177_{Hex}	375 pixels per horizontal line
Vertical line length	2	0271_{Hex}	625 horizontal lines
Image data length	4	00039387_{Hex}	234,375 bytes

Annex D
(informative)

Conditions for capturing finger image data

D.1 Purpose

This annex recommends techniques designed to enable the best possible fingerprint images to be captured from a scanner. It is intended for users of fingerprint image capture systems, as well as finger image capturing system designers and biometric authentication system designers. Descriptions in the document are targeted at the capture of high quality plain fingerprint images, but do not mandate anything about fingerprinting methods. Rolled finger impressions, such as those taken for law enforcement applications, are not the focus of this annex, as the capture of such prints is generally supervised by a trained operator to ensure correct placement and pressure. The term "confirmation" used in this document means making a final acceptance/rejection decision according to a visual inspection of a captured image. Specific decision criteria are not defined here, but some guidelines to make decisions are provided. System designers and system providers are recommended to adopt these guidelines as needed. Procedures to be executed when fingerprints image cannot be captured are beyond the scope of this document as are the techniques for the compression and encoding of captured images.

D.2 Fingerprint Imaging Recommendations

D.2.1 Recommendations for Finger Image Scanners (2Dimensional flat scanner)

D.2.1.1 Image Quality Specifications

It is recommended to use finger image capture devices that meet one or more of the certification specifications found in Table 5. Capture devices need to be re-calibrated periodically. The method by which this is done is device specific and beyond the scope of this standard. The frequency with which a device should be re-calibrated depends on both the vendor/device and the application for which it is being used, and will normally be defined as part of the standard operating procedures for the system.

D.2.1.2 Recommended Finger Positioning

Consistent finger positioning on the sensor surface makes it possible to acquire a larger effective image area from the same part of a finger every time. In other words, overlapped areas between images to be compared become larger, which is expected to improve the accuracy of verification.

The core of a fingerprint is defined as the topmost point on the innermost recurving ridgeline of a fingerprint. If the core is located at the centre of the captured image it will generally result in a larger overlapping area for verification purposes. For this purpose it may be beneficial to employ a display monitor where the finger positioning can be checked, or use devices with a function that automatically detects the finger position and provides appropriate feedback to the user. This will also prevent a device from capturing only a side of a fingertip.

Note that for some types of pattern classes the core is not located at the centre of the finger. In such cases, it may not be practical to use the core alignment method described above.

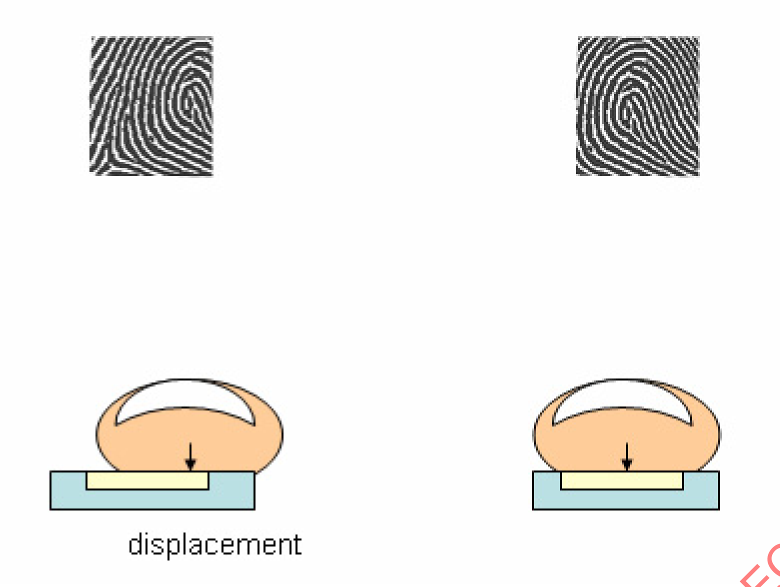


Figure D.1 — Centering finger

If directions of fingertips on the sensor surface are always the same, the overlapping area between two verification images will be consistent.

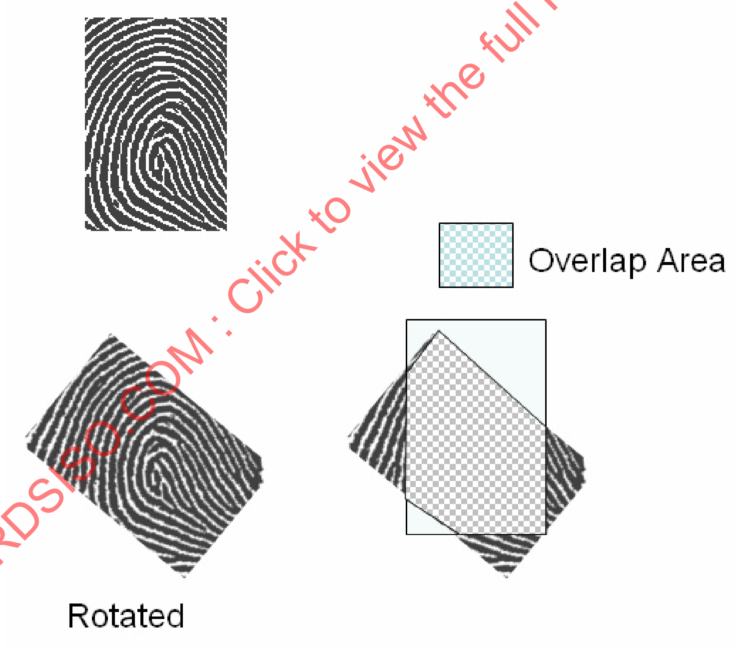


Figure D.2 — Rotation and its overlap area

Guidance (either visual or audible) for placing the finger in the same orientation each time should be provided, or the physical design of the device should be such as to encourage correct placement.

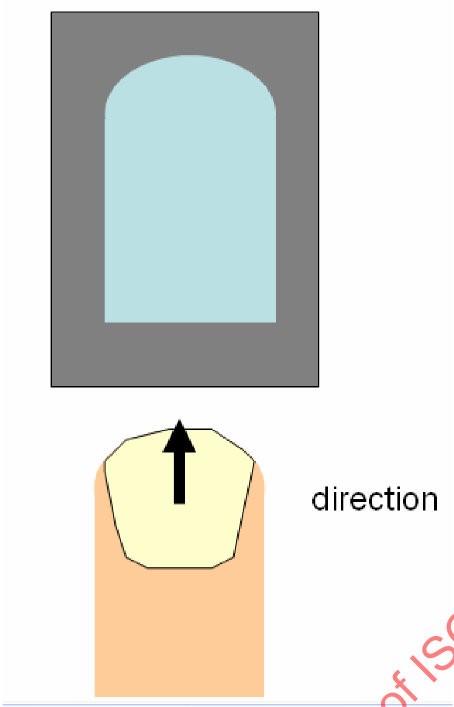


Figure D.3 — Fingertip direction

If a finger is placed at an angle to the sensor rather than placed flat on it, the side of the fingerprint will be captured and in general the utility of the sample will be reduced.

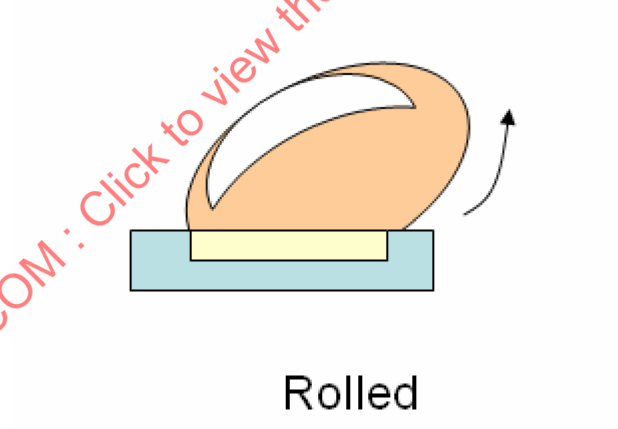


Figure D.4 — Angled finger

Decreasing such rolling motion is also necessary to improve the accuracy. Note that simultaneous capture of multiple fingers has an advantage of reducing the rolling motion.

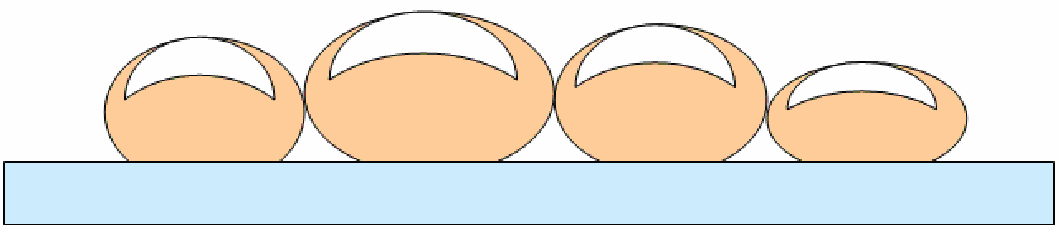


Figure D.5 — Multiple-finger slap

Automatic core-detection performance more or less depends on detection algorithm performance. On the other hand, while user cooperation will be required, slap fingerprints (simultaneous capture of four fingers) and the first joint position control may enable significant improvement once the users become familiar with the method.

D.2.1.3 Illumination, Lighting, Activation

Optical fingerprint sensors illuminate the finger when capturing it. However, ambient light may adversely affect the capture. For example a ceiling light may enter the sensor. This can be alleviated by providing a roof or other means to block the ambient light or using light with a wavelength range different from that of the ambient light. In the case where visible light is used to illuminate the sensor, turning this light on can be used as a cue to commence the capture process.

D.2.1.4 Cleanness of Platen, Latent Print

Before image capture device calibration, the capture platen shall be free of residual fingerprints. It is preferable to check whether any residual fingerprint may affect the subsequent capture. Excessive build up of dirt or residual fingerprints on the platen can adversely affect the quality of the captured image. The sensor should be cleaned in accordance with manufacturer's guidelines and agreed standard operating procedures for the application.

D.2.1.5 Moisturizing

Quality of a captured image may be degraded when the finger skin is very dry. 'If dry skin is thought to be resulting in low image quality for an individual, it may help to moisturise the finger, for example, by breathing on it, touching a sweaty part of the skin, wiping it with a wet paper, or applying gel or cream to it.

Note that if the finger is over-moisturized, the moisture may be captured on an image or leave a mark on the sensor surface. In that case, the sensor surface shall be dried by wiping off the moisture or by other means.

D.2.1.6 Drying

When a finger is very moist, it shall be wiped with a dry paper or air-dried. If excessively moist skin is thought to be resulting in low image quality for an individual, it may help to dry the finger.

D.2.1.7 Missing

There may be some cases where a fingerprint cannot be captured due to a missing finger or some other reasons. Appropriate policies need to be in place for handling such cases, depending on whether the situation is temporary (broken bone, injury, etc.) or permanent (amputation, physically-challenged, etc.).

D.2.1.8 Finger Selection and Order of Capture

It is preferable to provide screen display and/or audio guidance to provide instructions on finger selection and order, whether to capture the left hand only, right hand only, or both, and in the case of both hands, which hand to capture first. When more than one finger is to be captured, or a choice of finger is supported, the target finger(s) should be clearly indicated to the user, for example via diagrams or illustrations.

Alternative input rules shall be determined in advance in case there are fingers that cannot be captured. When the index finger is unavailable, for example, a rule of using the middle finger, thumb, or ring finger as an alternative, and the selection order of the alternative fingers should be determined. When capturing multiple fingers, switched fingers can be confirmed by using the verification function among each finger.

D.2.1.9 Assessing Finger Image Quality

Performance of any biometric system is highly dependent on the quality of data captured by the sensor.

Many fingerprint capture devices now include automated image quality assessment software to provide feedback to users, often in real time. Algorithms related to finger image quality are described in ISO/IEC TR 29794-4 and serve as references for quality value calculations adopted by device providers.

Another method is to capture several images from one finger and perform a cross comparison between them to see if the comparison scores obtained are above the threshold that has been set for the system. If they are, then the quality is sufficient for the intended application.

An extension of this approach is to plot the scores from all of the cross comparisons (see Figure 7); the image with the highest average score is assumed to have the highest image quality.

A benefit of assessing image quality at enrolment is that it can highlight problems where the subject's fingerprint characteristics are not of adequate quality for the intended application, thereby enabling appropriate countermeasures to be put in place (e.g. use a different finger, postpone the enrolment or consider using a different modality).

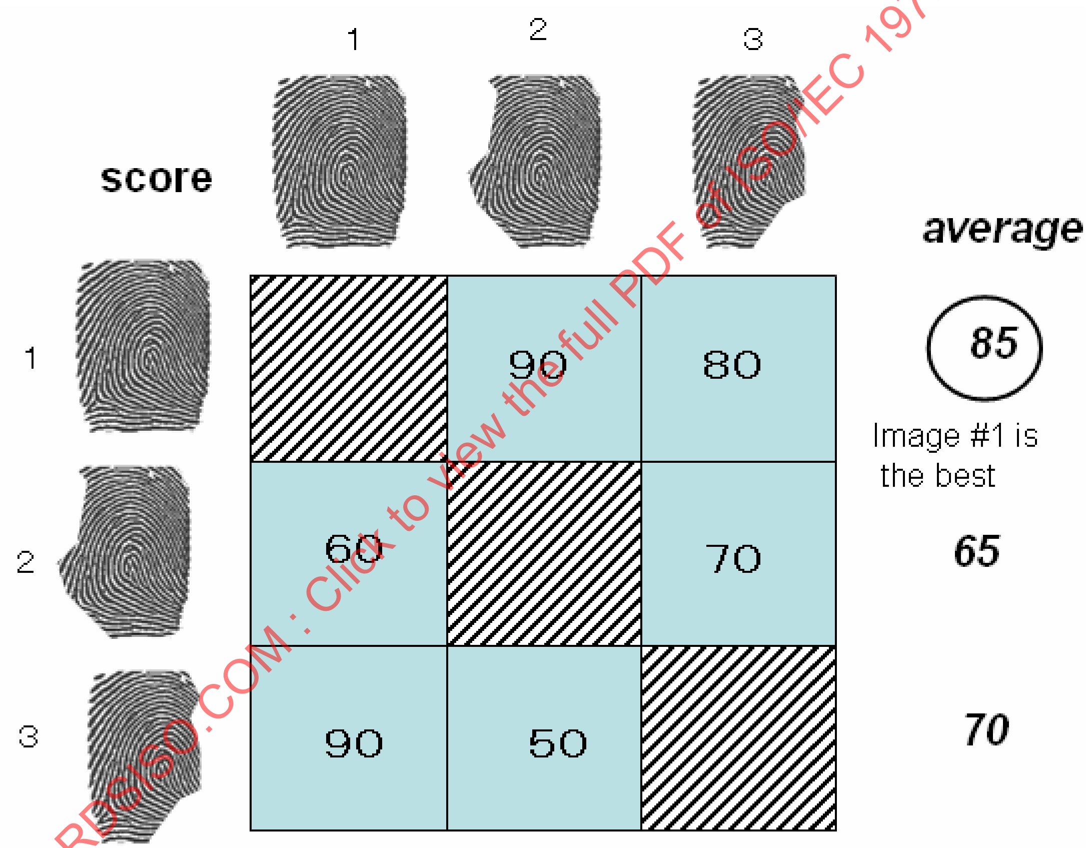


Figure D.6 — Selecting best image by using comparison trial average score

D.2.1.10 Existing Data Treatment

If an image of the finger was captured in the past, identification of the finger is possible by performing a comparison process. It may also be possible to find out that an image of a finger believed to not have been captured in the past is registered with a different ID.

D.2.1.11 Image Capture Factors

Height from the floor or the desktop to the scanner surface, as well as the angle of the scanner surface to the floor or the desktop, affects the quality of captured images. Other factors that affect quality are the number of fingers to be captured simultaneously (1, 2, 4, etc.) and whether both right and left hands are captured simultaneously or not.

Where enrolment is undertaken at multiple locations, it is highly desirable that comparable devices are used, not only in terms of image quality criteria (i.e. device certification such as App F, PIV), but also platen size, and capture processes. Controlling environmental variables such as the height and angle of the capture device will also help to ensure consistent capture quality.

Consideration shall also be given to the capture of fingerprints from those who are especially tall or short, as well as those with certain medical conditions or disabilities. The use of a portable or handheld sensor may make it easier to capture good quality fingerprint images from such subjects.

Positional relation between the sensor surface and the body also affects the quality of captured images. Usually, people tend to extend their hands with the thumb side up and the little finger side down. For this reason, a finger will be rolled (with the finger bone as an axis) when placing the finger on the sensor horizontal surface. This is not such an issue when capturing four fingers simultaneously, but when selecting the location for the capture device proper consideration should be given to these and other usability factors.

D.2.1.12 Operation

In some applications, and especially those where there is no operator supervision, the provision of clear instructions to users, perhaps by means of a monitor display or audio guidance, is desirable. Such guidance messages may include the following:

- Capture should start automatically.
- If a device rejects a captured image and requires another capture, recapturing process should be specifically notified to the user.
- If the capture does not succeed even after a defined number of attempts, the device should indicate that the user needs to take other measures.

D.2.1.13 Example Configurations

D.2.1.13.1 One Finger in a Standing Position

Image capture of one finger in a standing position is illustrated below.

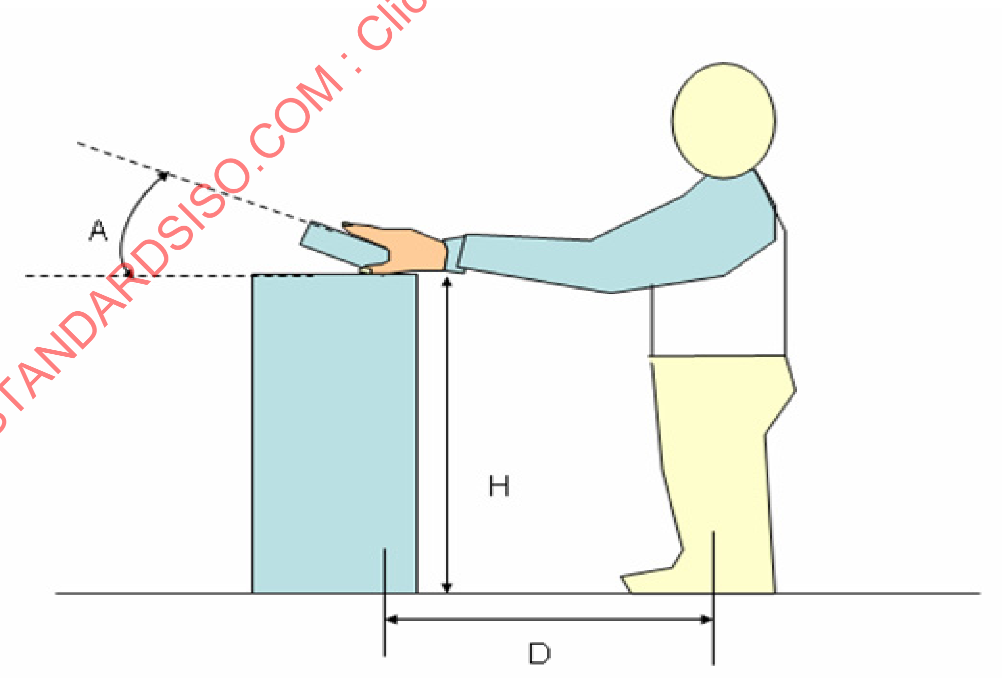


Figure D.7 — Standing position

Parameters such as height from the floor(H), angle(A), relative position between the body and the device(D), and other necessary item should be described in the design specification.

D.2.1.13.2 Four Fingers in a Sitting Position

Image capture of four fingers in a sitting position is illustrated below. Same as in the case of one finger.

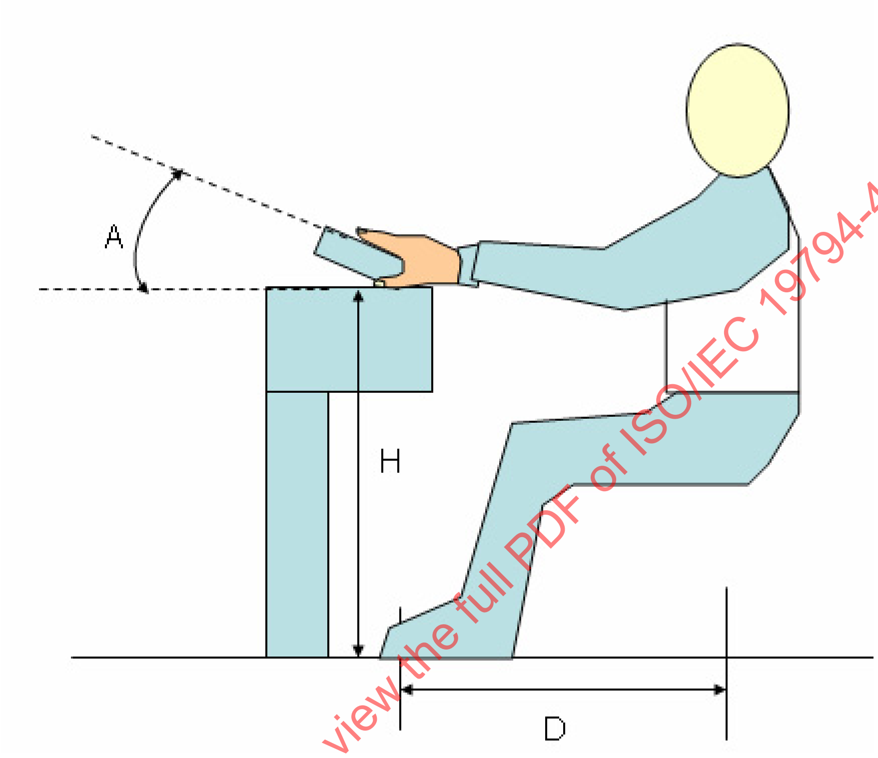


Figure D.8 — Sitting position

D.2.1.14 Indications to biometric operational personnel

More than one decision threshold is applied to comparison scores in some systems, for example in those which return a decision of “unknown” in addition to “comparison” and “non-comparison”. When a comparison score is not sufficient due to image quality, it may be possible to reduce doubt about the verification result by presenting the quality value of the captured image to the operator if present.

D.2.1.15 Confirmation

The following may become possible by operators of the capturing system making a final decision when the automatic judgment is not sufficient:

- To check if the user correctly understands the capture procedure, or
- To visually check images based on highly-detailed information other than minutiae, for example whether the effective area is small or not.

D.3 Guidelines for Image Data

D.3.1 Image Quality Metrics

Algorithms related to finger image quality described in ISO/IEC TR 29794-4 serve as references for quality value calculation algorithms that are adopted in system specifications by providers.

There have been attempts to detect the center of the pattern of a finger image area. System providers can consider introducing this function to the system specifications.

There have been attempts to calculate image quality using the reliability of minutiae detection. System providers can consider introducing this function to the system specifications.

D.3.2 Human Interface (Displaying Capturing/Captured Image)

When users are cooperative, it may be better to make the captured images visible to them. When there is a concern about fingerprint image being peeped from a security perspective, presentation of a captured image may be avoided. In this case, an illustration can be presented instead.

D.3.3 Preprocessing

Some devices are provided with a function to capture higher-quality images by automatically altering sensor parameters to deal with sensor characteristic changes due to aging or to adapt to more variations of skin conditions. However, the capture process may take longer in order to implement parameter changes. Raw data captured by a sensor may be processed and enhanced to improve visualization. However, detailed grayscale information can be lost due to the enhancement.

D.4 Finger Image Quality Assessment Software

Capture software is expected to have the following features:

- Indication of the start of capture which is that time that begins at the point when the subject places their hand on the platen
- Instruction of the capture sequence
- Selection of high-quality images according to automatic quality judgment
- Retry instruction after failed capture
- Software for automatic quality judgment function (vendors, product names, versions, etc.) should be specified
- Software for feature extraction should be specified
- Software for verification should be specified
- Comparison for trial at a registration function, and
- Selection of best quality image using a trial comparison function.

D.5 Law enforcement finger size recommendations

Table D.1 provides guidance and recommendations for the capture size of single fingers and the combination of the index, middle, ring, and little fingers from each hand. The values shown are aimed at the law enforcement application.

Table D.1 — Guidance for finger sizes

Finger position	Finger code	Max image area (cm^2)	Width		Length	
			(mm)	(in)	(mm)	(in)
Unknown	0	15,47	40,6	1,6	38,1	1,5
Right thumb	1	15,47	40,6	1,6	38,1	1,5
Right index finger	2	15,47	40,6	1,6	38,1	1,5
Right middle finger	3	15,47	40,6	1,6	38,1	1,5
Right ring finger	4	15,47	40,6	1,6	38,1	1,5
Right little finger	5	15,47	40,6	1,6	38,1	1,5
Left thumb	6	15,47	40,6	1,6	38,1	1,5
Left index finger	7	15,47	40,6	1,6	38,1	1,5
Left middle finger	8	15,47	40,6	1,6	38,1	1,5
Left ring finger	9	15,47	40,6	1,6	38,1	1,5
Left little finger	10	15,47	40,6	1,6	38,1	1,5
Plain right four fingers	13	61,95	81,3	3,2	76,2	3,0
Plain left four fingers	14	61,95	81,3	3,2	76,2	3,0
Plain thumbs (2)	15	61,95	81,3	3,2	76,2	3,0

D.6 Possible References

Recommend to check reference literatures for following issues:

- Recommended selection of fingers and order based on statistical experimental results
- Minimum image size for good comparison performance and
- Significance of statistical logging and checking quality values (to be used for consideration of revising capture sequence, standards, software, threshold and others).

Annex E
(normative)

WSQ Gray-scale fingerprint image compression specification

E.1 Requirements and guidelines

E.1.1 General

This Specification is applicable to continuous-tone gray-scale digital fingerprint images. This specification

- Specifies a class of encoders for converting source fingerprint image data to compressed image data;
- Specifies a decoder process for converting compressed image data to reconstructed fingerprint image data;
- Specifies coded representations for compressed image data.

E.1.2 Introduction

E.1.2.1 Wavelet Scalar Quantization (WSQ) Compression

The WSQ class of encoders involves a decomposition of the fingerprint image into a number of subbands, each of which represents information in a particular frequency band. The subband decomposition is achieved by a *discrete wavelet transformation* (DWT) of the fingerprint image.

Each of the subbands is then *quantized* using values from a *quantization table*. No default values for quantization tables are given in this Specification.

The quantized coefficients are then passed to a *Huffman encoding* procedure which compresses the data. *Huffman table* specifications shall be provided to the encoder.

Figure E.1 shows the main procedures for WSQ encoding and decoding. The same tables specified for an encoder to use to compress a particular image shall be provided to a decoder to reconstruct that image.

E.1.2.2 Structure of compressed data

Compressed image data is described by a uniform structure and a set of parameters. The various parts of the compressed image data are identified by special two-byte codes called *markers*. Some markers are followed by particular sequences of parameters such as table specifications and headers. Others are used without parameters for functions such as marking the start-of-image and end-of-image. When a marker is associated with a particular sequence of parameters, the marker and its parameters comprise a *marker segment*.

The data created by the *entropy encoder* are also segmented, and one particular marker - the *restart marker* - is used to isolate *entropy-coded data segments*. The encoder outputs the restart markers, intermixed with the entropy-coded data, between certain subband boundaries. Restart markers can be identified without having to decode the compressed data to find them. Because they can be independently decoded, entropy-coded data segments provide for progressive transmission, and isolation of data corruption.

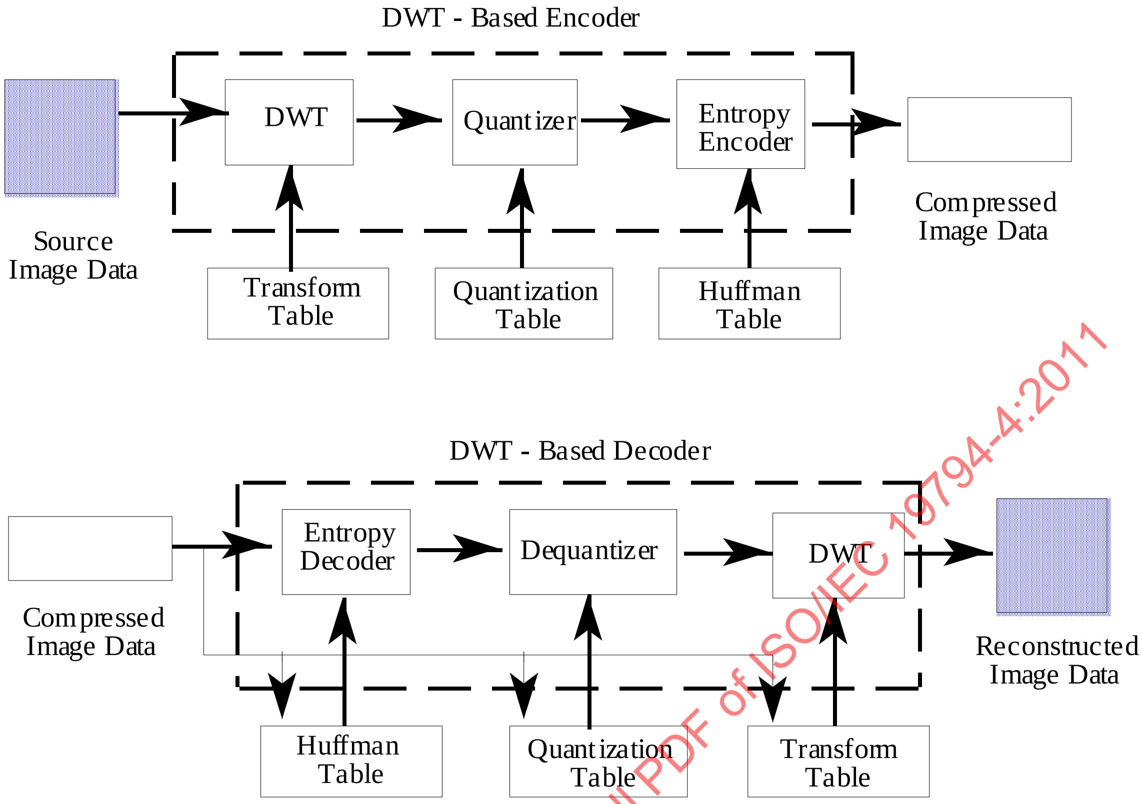


Figure E.1 — DWT-based encoder and decoder simplified diagram

E.1.2.3 Interchange format

In addition to certain required marker segments and the entropy-coded segments, the interchange format shall include the marker segments for all filter coefficient, quantization, and entropy-coding tables needed by the decoding process. This guarantees that a compressed image can cross the boundary between identification systems, regardless of how each environment internally associates tables with compressed image data.

E.1.2.4 Abbreviated format for compressed image data

The abbreviated format for compressed image data is identical to the interchange format, except that it does not include all tables required for decoding (it may include some of them). This format is intended for use within applications where alternative mechanisms are available for supplying some or all of the table-specification data needed for decoding.

E.1.2.5 Abbreviated format for table-specification data

This format contains only table-specification data. It is a means by which the application may install in the decoder the tables required to subsequently reconstruct one or more fingerprint images.

E.1.3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19794-1 and the following apply.

E.1.3.1
bit stream
partially encoded or decoded sequence of bits comprising an entropy-coded segment

E.1.3.2
byte stuffing
procedure in which the Huffman coder inserts a zero byte into the entropy-coded segment following the generation of an encoded FF_{Hex} byte

E.1.3.3
coding model
procedure used to convert input data into symbols to be coded

E.1.3.4
coding process
general term for referring to an encoding process, a decoding process, or both

E.1.3.5
columns
samples per line in an image

E.1.3.6
compressed data
either compressed image data or table specification data or both

E.1.3.7
compressed image data
coded representation of an image, as specified in this Specification

E.1.3.8
compression
reduction in the number of bits used to represent source image data

E.1.3.9
continuous-tone image
image sampled at 8 bits per pixel

E.1.3.10
decoder
embodiment of a decoding process

E.1.3.11
decoding process
process which takes as its input compressed image data and outputs a continuous-tone image

E.1.3.12
dequantization
inverse procedure to quantization by which the decoder recovers a representation of the DWT coefficients

E.1.3.13
(digital) reconstructed image (data)
continuous-tone image which is the output of the decoder defined in this Specification

E.1.3.14
(digital) source image (data)
continuous-tone image used as input to any encoder defined in this Specification

E.1.3.15
(digital) image (data)
two-dimensional array of data

E.1.3.16
downsampling
procedure by which the spatial resolution of an image is reduced

E.1.3.17
DWT discrete wavelet transform)
linear transformation, implemented by a multirate filter bank, that maps a digital input signal to a collection of output subbands

E.1.3.18
encoder
embodiment of an encoding process

E.1.3.19
encoding process
process which takes as its input a continuous-tone image and outputs compressed image data

E.1.3.20
entropy-coded (data) segment
independently decodable sequence of entropy encoded bytes of compressed image data

E.1.3.21
entropy decoder
embodiment of an entropy decoding procedure

E.1.3.22
entropy decoding
lossless procedure which recovers the sequence of symbols from the sequence of bits produced by the entropy coder

E.1.3.23
entropy encoder
embodiment of an entropy encoding procedure

E.1.3.24
entropy encoding
lossless procedure which converts a sequence of input symbols into a sequence of bits such that the average number of bits per symbol approaches the entropy of the input symbols

E.1.3.25
Huffman decoder
embodiment of a Huffman decoding procedure

E.1.3.26
Huffman decoding
entropy decoding procedure which recovers the symbol from each variable length code produced by the Huffman encoder

E.1.3.27
Huffman encoder
embodiment of a Huffman encoding procedure

E.1.3.28
Huffman encoding
entropy encoding procedure which assigns a variable length code to each input symbol

E.1.3.29
Huffman table
set of variable length codes required in a Huffman encoder and Huffman decoder

E.1.3.30
image data
either source image data or reconstructed image data

E.1.3.31
interchange format
representation of compressed image data for exchange between application environments

E.1.3.32
lossless
descriptive term for encoding and decoding processes and procedures in which the output of the decoding procedure(s) is identical to the input to the encoding procedure(s)

E.1.3.33
marker
two-byte code in which the first byte is FF_{Hex} and the second byte is a value between 1 and FE_{Hex}

E.1.3.34
marker segment
marker and associated set of parameters

E.1.3.35
parameters
fixed length integers 8, 16, or 32 bits in length, used in the compressed data format

E.1.3.36
procedure
set of steps which accomplishes one of the tasks which comprise an encoding or decoding process

E.1.3.37
progressive (coding)
separation of data segments into blocks that can be transmitted successively to allow the compressed image data to be decoded at successively higher levels of resolution

E.1.3.38
quantization table
set of quantization values (i.e., bin widths) used to quantize DWT coefficients within the subbands

E.1.3.39
quantize
act of performing the quantization procedure for a DWT coefficient

E.1.3.40
reference inverse SWT
double precision floating point implementation of the inverse SWT defined in Clause E.2 of this Specification

E.1.3.41
reference SWT
double precision floating point implementation of the SWT defined in Clause E.2 of this Specification

E.1.3.42
restart interval
number of coefficients processed as an independent sequence within an image

E.1.3.43
restart marker
marker that separates two restart intervals in an image

E.1.3.44
run (length)
number of consecutive symbols of the same value

E.1.3.45
SWT (symmetric wavelet transform)
linear transform implemented by applying a DWT to a periodized symmetric extension of the input signal

E.1.3.46
sample
one element in the two-dimensional array which comprises a fingerprint image

E.1.3.47
table specification data
coded representation from which the tables, used in the encoder and decoder, are generated

E.1.3.48
upsampling
procedure by which the spatial resolution of an image is increased

E.1.4 Requirements

E.1.4.1 Interchange format requirements

The interchange format is the coded representation of compressed image data for exchange between application environments.

The interchange format requirements are that any compressed image data represented in interchange format shall comply with the syntax and codes assignments for the decoding process, as specified in Clause E.3.

E.1.4.2 Encoder requirements

An encoder process converts source fingerprint images to compressed image data. An encoder is an embodiment of the encoding process specified in Clause E.2. To comply with this Specification, an encoder shall satisfy at least one of the following two requirements:

- Convert source fingerprint image data to compressed image data which complies with the interchange format syntax specified in Clause E.3 with proper accuracy, and
- Convert source fingerprint image data to compressed image data which complies with the abbreviated format syntax for compressed image data specified in Clause E.3 with proper accuracy.

E.1.4.3 Decoder requirements

A decoding process converts compressed image data to reconstructed image data. A decoder is an embodiment of the decoding process specified in Clause E.2. To comply with this Specification, a decoder shall satisfy all three of the following requirements:

- Convert to reconstructed fingerprint image data any compressed image data with parameters that comply with the interchange format syntax specified in Clause E.3 with proper accuracy
- Accept and properly store any table-specification data which complies with the abbreviated format syntax for table-specification data specified in Clause E.3, and
- Convert to reconstructed fingerprint data any compressed image data which complies with the abbreviated format syntax for compressed image data specified in Clause E.3 with proper accuracy, provided that the table-specification data required for decoding the compressed image data has previously been installed into the decoder.

E.2 Mathematical definitions

E.2.1 Source fingerprint image

Source fingerprint images shall be captured with 8 bits of precision per pixel. Before the encoding process computes the discrete wavelet transform (DWT) for the image, the samples, $I(m,n)$, shall be transformed in accordance with the following equation:

$$I'(m,n) = \frac{[I(m,n) - M]}{R} \qquad \begin{array}{l} 0 \le m \le Y-1 \\ 0 \le n \le X-1 \end{array}$$

The image width (X) and height (Y) parameters are defined in Clause E.3.2.2. The decoding process shall apply an inverse transformation to restore the samples to their original scale. The midpoint and rescale parameters, M and R, are specified by the encoder and transmitted in the compressed image data.

E.2.2 Subband coding of fingerprint images

E.2.2.1 Two-channel subband coder (in one dimension)

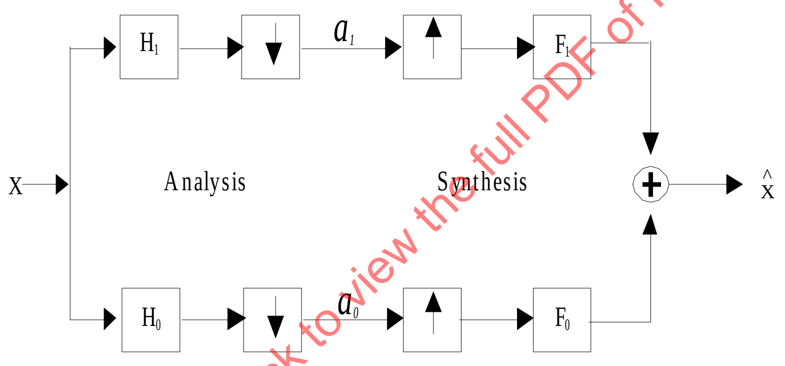


Figure E.2 — Two-Channel subband coder

A two-channel subband encoder is a digital filter bank of the type shown in Figure E.2. It should be regarded as a pair of systems, the analysis bank and the synthesis bank. The subband coder provides zero distortion, $\hat{x}(n) = x(n)$.

The boxes H_i and F_i denote linear time-invariant digital filters [10], while ↓ and ↑ denote 2:1 down- and up-sampling operations:

$$(x * h)(k) = \sum_n x(n)h(k-n),$$

$$(\downarrow y)(k) = y(2k),$$

$$(\uparrow a)(k) = \begin{cases} a(k/2), & k \text{ even} \\ 0, & k \text{ odd} \end{cases}$$

The transform defined by the analysis bank, $x \rightarrow \{a_0, a_1\}$, will be referred to as a one-dimensional DWT, and the transform given by the synthesis bank as the inverse DWT.

E.2.2.1.1 Linear Phase Wavelet Filters

This standard utilizes two distinct classes of linear phase finite impulse response (FIR) filters. We let h_0 denote the lowpass filter and h_1 the highpass filter in a filter bank. The first class will contain pairs of odd-length, symmetric filters (i.e., filters whose impulse responses are symmetric about their middle sample). These are called “Type I” linear phase FIR filters, [10], or whole-sample symmetric (WSS) filters. The second class will contain pairs of even-length filters, one symmetric (the lowpass filter) and one antisymmetric (the highpass filter). These are called, respectively, “Type II” and “Type IV” filters, [10]; since such filters are symmetric about the point halfway between their middle two samples, we shall also refer to them as half-sample symmetric/antisymmetric (HSS/HSA or HS-type) filters.

The compressed data format described in Clause E.3 provides only for the transmission of impulse response coefficients from the right halves of the analysis filters; the synthesis filters are completely determined by the following anti-aliasing relations:

$$f_0(n)=(-1)^n h_1(n-1) \text{ and}$$
$$f_1(n)=(-1)^{n-1} h_0(n-1).$$

For a WSS analysis bank, the lowpass filter, h_0, shall be symmetric about 0, i.e., h_0 runs from $h_0(-r_0)$ to $h_0(r_0)$. Using the syntax of Clause E.3.2.4.1, the length of h_0 is $L0 = 2\ r_0$+l. The transform table specified in Clause E.3.2.4.1 contains the impulse response coefficients from the right half of h_0:

$$H0_1 = h_0(0),\ H0_2 = h_0(1),\ \ldots\ ,\ H0_{last} = h_0(t_0).$$

The left half of h_0 is given by the symmetry relation $h_0(-n) = h_0(n)$. The highpass filter, h_1, in a WSS analysis bank shall be symmetric about -1. The transmitted coefficients are:

$$H1_1 = h_1(-1),\ H1_2 = h_1(0),\ \ldots\ ,\ H1_{last} = h_1(r_1 - 1),$$

where $L1 = 2r_l+1$; the left half of h_1 is given by the symmetry relation $h_1(-1-n) = h_1(n-1)$.

For an HS-type analysis bank, both filters shall be centered at -1/2, and thus run from $h_i(-r_i)$ to $h_i(r_i-1)$, where the length of h_i is $Li = 2r_i$. The transmitted values are: (i = 0,1)

$$Hi_1 = h_i(0),\ Hi_2 = h_i(1),\ \ldots\ ,\ Hi_{last} = h_i(r_i - 1).$$

The lowpass filter, h_0, is symmetric (HSS), so the left half of h_0 is given by the symmetry relation $h_0(-l-n) = h_0(n)$. The highpass filter, h_1, is antisymmetric (HSA), so the left half of h_1 is given by the symmetry relation $h_1(-1-n) = -h_1(n)$.

E.2.2.1.2 Constraints on Filter Length

Encoders and decoders shall be capable of forming (or inverting) the subband decomposition specified in Figure E.6 using filters of lengths up to and including the maximum values

$L_{max} = 31$ for WS-type filters,

$L_{max} = 32$ for HS-type filters.

E.2.2.2 Symmetric boundary conditions for the DWT

The generic input, $x(n)$, to Figure E.2 will, in practice, be a row or column vector from an image or from one of its DWT subbands. To describe precisely how a finite-length signal is transformed by the system depicted in Figure E.2, we use the following conventions for indexing and extrapolating x. All WSQ decoders shall be capable of decoding a compressed signal encoded in accordance with these conventions. x is assumed to run from $x(0)$ to $x(N_0-1)$, where N_0 is the (generic) length of x.

For transformation by WSS filters, x is extended to a whole-sample symmetric signal, $y = E_s^{(1,1)}x$, of length $N = 2N_0 - 2$, and periodized. For HS-type filters, x is extended to a half-sample symmetric signal, $y = E_s^{(2,2)}x$, of length $N = 2N_0$, and periodized. In each case, the filters are extended with zeros to length N and applied by N-periodic circular convolution; see Figure E.3.

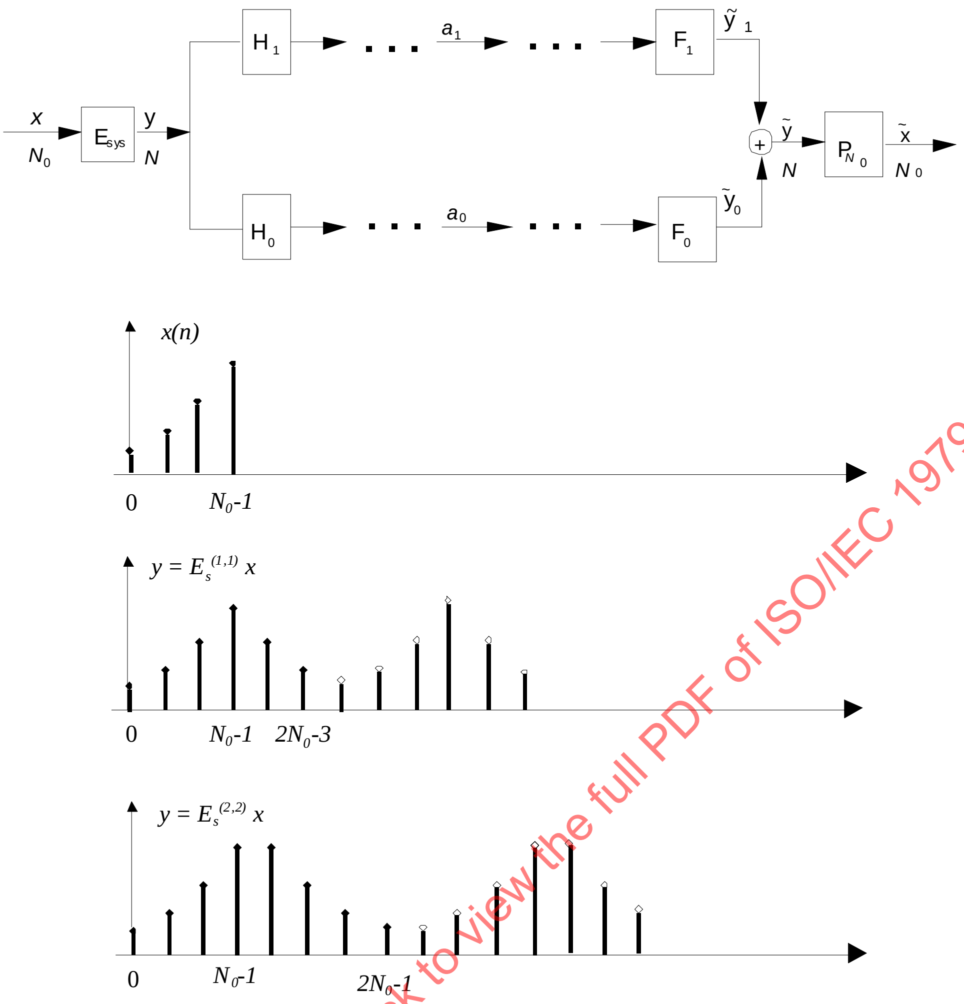


Figure E.3 — Symmetric DWT extension

With the choices of filter and signal symmetries described above, this system generates symmetric DWT subbands, of which only the first half (now denoted a_i) needs to be computed and stored. For instance, with WSS filters and N_0 even, the coefficients

$$a_i(k) = \sum_{n=0}^{N-1} y(n) h_i(2k - n)$$

only need to be computed and stored for $k = 0, ..., N_0/2 - 1$, even though

$$b_i = \downarrow (y * h_i)$$

has period $N/2 = N_0 - 1$. This is possible because b_i is itself symmetric and can be reconstructed from the first $N_0/2$ values, $a_i(k)$.

The sequences a_i generated in this fashion can in turn be extended to whole- or half-sample symmetric signals and cascaded back through the analysis bank, Figure E.3, to achieve a multiband decomposition of the input. The composition of mappings

$$x \xrightarrow{E_{sys}} y \xrightarrow{DWT} \{a_o, a_1\}$$

will be referred to as a one-dimensional symmetric wavelet transform (SWT) [7]. Note that, in spite of the extension of the input signal, x, the SWT still maps an input of length N_0 to a pair of subbands $\{a_0, a_l\}$ containing a total of just N_0 values. When N_0 is odd, a_0 will have length $(N_0 + 1)/2$, and a_1 will have length $(N_0 - 1)/2$ for both WSS and HS-type extensions.

E.2.2.2.1 Symmetric Subband Synthesis

This clause describes the symmetry properties of the subbands $b_i = \downarrow (y*h_i)$, giving the number of nonredundant samples that need to be transmitted,

$$a_i(k) = b_i(k); \quad 0 \le k \le \rho_i - 1,$$

and specifies the procedures for extending the quantized transmitted coefficients in the decoding process:

$$\hat{b}_i = E_i \hat{a}_i; \quad \hat{y}_i = f_i * (\uparrow \hat{b}_i).$$

We begin by introducing some terminology for describing symmetric signals like those shown in Figure E.3. If an N-periodic signal is symmetric about n=0 then it is also necessarily symmetric about $n = N/2$; cf. $y = E_s^{(l,l)}x$ in Figure E.3 for $N = 2N_0$-2. When N is even, such signals are called "(1,1)-symmetric" since they are whole-sample symmetric about both centers. Similarly, an N-periodic signal symmetric about -1/2 is also necessarily symmetric about $(N$-1)/2; cf. $y = E_s^{(2,2)}x$ in Figure E.3 for N=2N_0. When N is even, such signals are called "(2,2)-symmetric" since they are half-sample symmetric about both centers. When N is odd, we get signals that are WSS about one center and HSS about the other; such signals are called "(1,2)-symmetric" if they are WSS about 0, and "(2,1)-symmetric" if they are HSS about -1/2. There are obvious antisymmetric analogues of these symmetry properties.

Given a signal $w(n)$, $0 \le n \le K$-1, let $E_s^{(i,j)}w$ (resp., $E_a^{(i,j)}w$) denote the (i,j)-symmetric (resp., (i,j)-antisymmetric) extension of $w(n)$, where i,j = 1 or 2, generalizing the two extensions shown in Figure E.3 for w=x. If a subband $b(k)$ is (i,j)-symmetric and

$$a(k) = b(k); \quad 0 \le k \le \rho - 1$$

is a complete, nonredundant half-period of b, then b can be reconstructed from a via the extension $b = E_s^{(i,j)}a$. A similar statement holds for antisymmetric subbands. Since the symmetry of b is completely determined by the symmetry of the extension $y = E_{sys}x$ and the symmetry of the analysis filter, h, it suffices to quantize and transmit only the half-period, a, reconstructing b in the decoder using a known extension operator, E. This method of applying a DWT filter bank to a finite-duration input signal, x, is referred to as the symmetric wavelet transform (SWT) algorithm; a detailed treatment is presented in [7].

Table E.1 lists the symmetry properties of the subbands, b, and their "ranks" ρ, which specifies the number of coefficients, a (k), that need to be transmitted. The table is divided into two cases: one case for WSS filter banks, which use the analysis extension $y = E_s^{(l,l)}x$ (the "(1,1)-SWT"), and a second case for HS-type filter banks, which use the analysis extension $y = E_s^{(2,2)}x$ (the "(2,2)-SWT"). These filter banks are described above in E.2.2.1.1.

Table E.1 — Symmetry, rank of SWT subbands

		Case 1: WSS Filters Input Length, N_0		**Case 2: HS-Type Filters Input Length, N_0**	
		Even	Odd	Even	Odd
Filter	h_0	(1,2) - sym. $\rho_0 = N_0/2$	(1,1) - sym. $\rho_0 = (N_0 + 1)/2$	(2,2) - sym. $\rho_0 = N_0/2$	(2,1) - sym. $\rho_0 = (N_0 + 1)/2$
	h_1	(2,1) - sym. $\rho_1 = N_0/2$	(2,2) - sym. $\rho_1 = (N_0 - 1)/2$	(2,2) - antisym. $\rho_1 = N_0/2$	(2,1) - antisym. $\rho_1 = (N_0 - 1)/2$

E.2.2.3 Wavelet decomposition in two dimensions

The tree structure for a single level of a 2-dimensional image decomposition system is depicted in Figure E.4. The row vectors of the image are filtered by applying the SWT algorithm described in the preceding clause. The same procedure is then applied to the column vectors of the resulting array, giving a decomposition into four subbands, as shown in Figure E.5. Note that the pair of indices indicates which filters were applied to the rows and columns of the signal. For instance, a_{10} has been highpass-filtered on rows and lowpass-filtered on columns, so it contains vertical edge features. The filters applied in succeeding levels of filter bank cascade are indicated with succeeding pairs of binary indices.

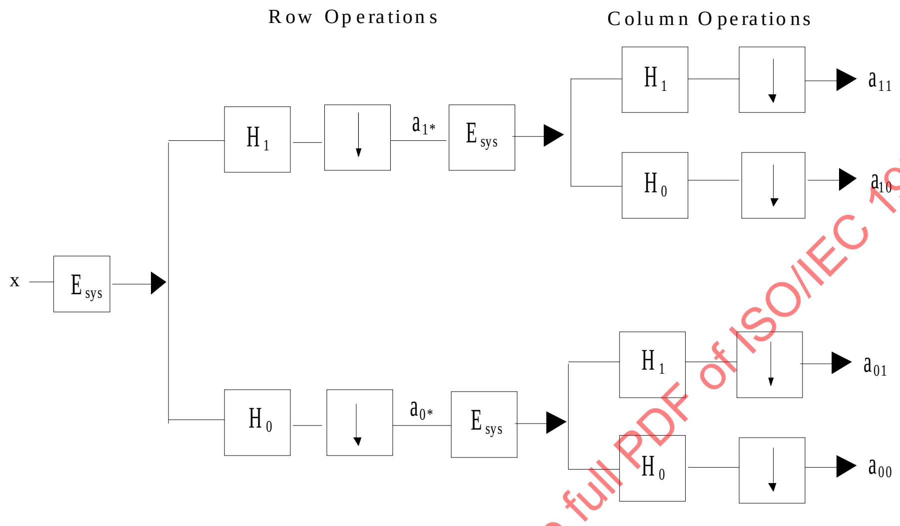


Figure E.4 — Single-Level, two-dimensional subband analysis

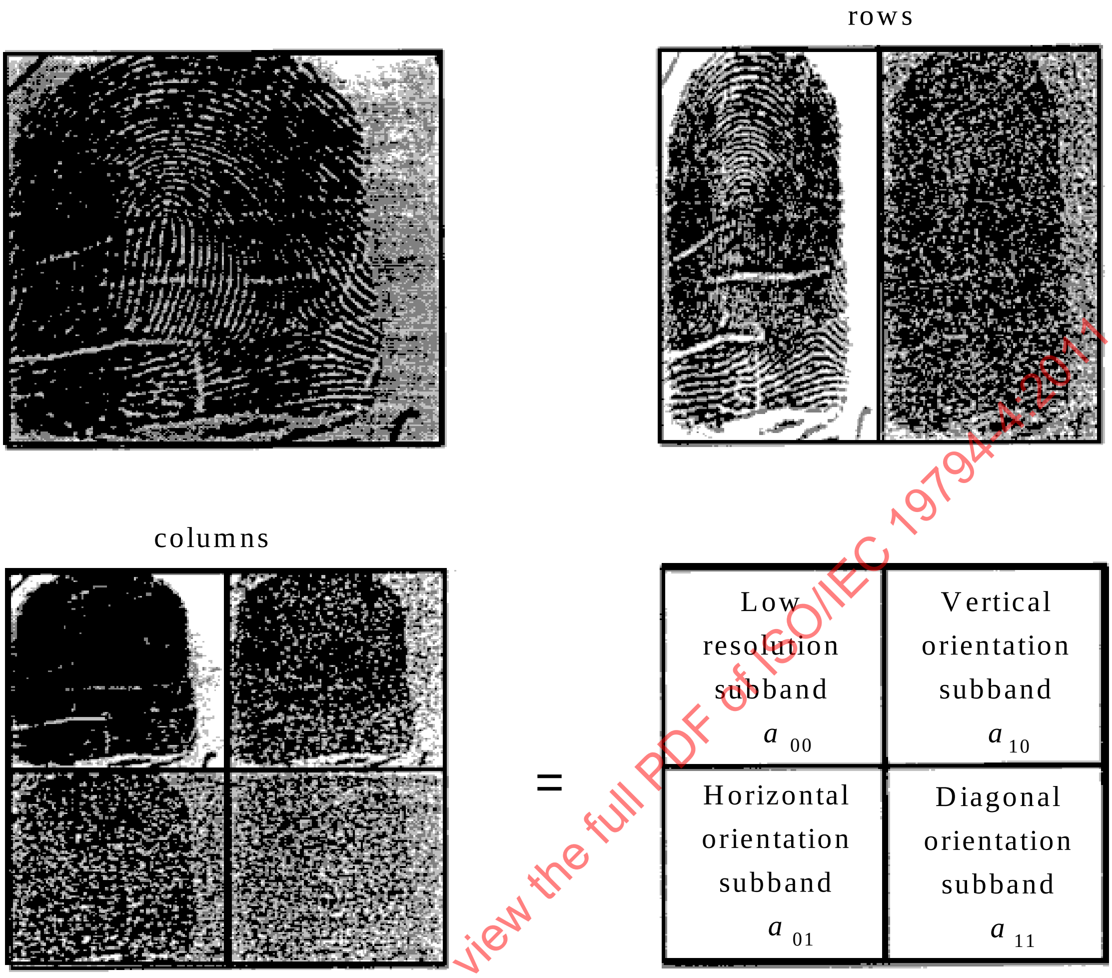
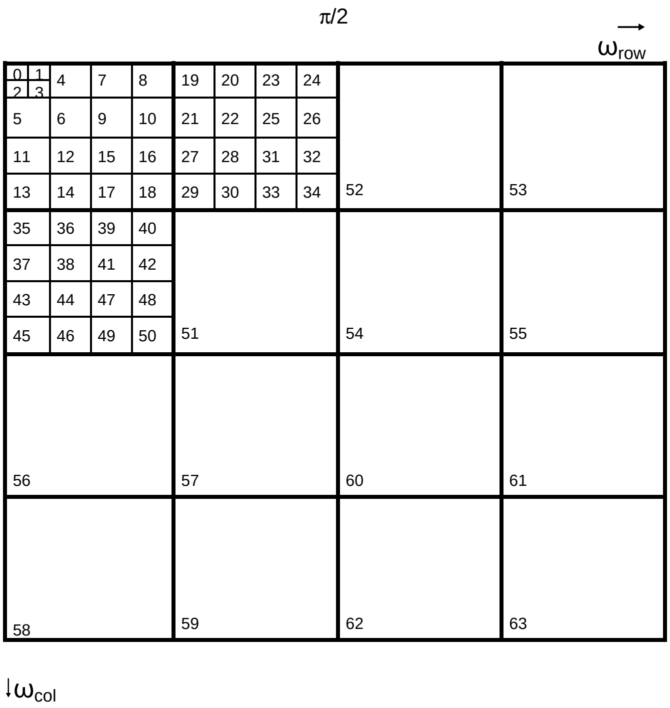


Figure E.5 — Four Subband decomposition

E.2.2.4 Subband structure

After the first level of decomposition shown in Figure E.4, any of the resulting four subbands may be cascaded back through the filter bank to further split the subband into four more subbands. This process is continued until the desired subband structure is obtained. Figure E.6 is the subband structure specified for fingerprint images by this Specification. The table shows which filters are applied to obtain each subband.



Filter Bank Path

0	00,00,00,00,00	22	00,10,10,11	44	00,01,00,11
1	00,00,00,00,10	23	00,10,00,10	45	00,01,00,00
2	00,00,00,00,01	24	00,10,00,00	46	00,01,00,10
3	00,00,00,00,11	25	00,10,00,11	47	00,01,10,11
4	00,00,00,10	26	00,10,00,01	48	00,01,10,01
5	00,00,00,01	27	00,10,11,01	49	00,01,10,10
6	00,00,00,11	28	00,10,11,11	50	00,01,10,00
7	00,00,10,10	29	00,10,11,00	51	00,11
8	00,00,10,00	30	00,10,11,10	52	10,10
9	00,00,10,11	31	00,10,01,11	53	10,00
10	00,00,10,01	32	00,10,01,01	54	10,11
11	00,00,01,01	33	00,10,01,10	55	10,01
12	00,00,01,11	34	00,10,01,00	56	01,01
13	00,00,01,00	35	00,01,01,00	57	01,11
14	00,00,01,10	36	00,01,01,10	58	01,00
15	00,00,11,11	37	00,01,01,01	59	01,10
16	00,00,11,01	38	00,01,01,11	60	11,11
17	00,00,11,10	39	00,01,11,10	61	11,01
18	00,00,11,00	40	00,01,11,00	62	11,10
19	00,10,10,00	41	00,01,11,11	63	11,00
20	00,10,10,10	42	00,01,11,01		
21	00,10,10,01	43	00,01,00,01		

Figure E.6 — Subband decomposition

E.2.3 Quantization

After the subband decomposition is computed the resulting coefficients are quantized uniformly within subbands. The quantizer zero bin width and the step size for each subband are contained in the quantization table. A quantization step size of zero ($Q_k = 0$) indicates that all coefficients within the subband are zero and the subband is not transmitted. The following equation would apply to the wavelet coefficients $a_k(m,n)$ in subband k.

$$p_k(m,n) = \begin{cases} \left\lfloor \dfrac{a_k(m,n) - Z_k/2}{Q_k} \right\rfloor + 1, & a_k(m,n) > Z_k/2 \\ 0, & -Z_k/2 \le a_k(m,n) \le Z_k/2 \\ \left\lceil \dfrac{a_k(m,n) + Z_k/2}{Q_k} \right\rceil - 1, & a_k(m,n) < -Z_k/2 \end{cases}$$

At the decoder**,** the following equation dequantizes the indices. The value C determines the quantization bin centers.

$$\hat{a}_k(m,n) = \begin{cases} (p_k(m,n) - C)Q_k + Z_k/2, & p_k(m,n) > 0 \\ 0, & p_k(m,n) = 0 \\ (p_k(m,n) + C)Q_k - Z_k/2, & p_k(m,n) < 0 \end{cases}$$

Z_k is the width of the center (zero) quantization bin and Q_k is the width of the nonzero quantization bins in the k^{th} subband. The function $\lceil x \rceil$ is the least integer greater than or equal to *x*, and $\lfloor x \rfloor$ is the greatest integer less than or equal to *x*.