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Information Technology — Biometric data interchange Formats — Part 2: Finger minutiae data

Technologie de l'Information — Formats d'échanges de données biométriques — Partie 2: Dates des minuties du doigt

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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 19794-2 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 37, *Biometrics*.

This second edition revises the first edition (ISO/IEC 19794-2:2005). This edition reflects the harmonization across the second generation of 19794. A new clause 7 has been added to describe the Finger Minutiae Format Types; clause 8 contains descriptions of the harmonized general and representation headers; and clauses 8 and 9 have been technically revised. All annexes have been technically revised. Annex A is under development and will contain an amendment for Conformance Testing Methodology for this part of 19794. The former Annex B Fingerprint Image Quality Specifications has been removed. Annex E contains three examples of Capture Device Certifications. Annex F provides descriptions of fingerprint minutiae location, direction, and type.

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

This part of ISO/IEC 19794 is one of a family of international standards being developed by ISO/IEC JTC1/SC 37 that support interoperability and data interchange among biometric applications and systems. This family of standards 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 this family of standards is provided in ISO/IEC 19794-1 Biometric data interchange formats – Part 1: Framework.

In the interest of implementing interoperable biometric recognition systems, this part of ISO/IEC Standard establishes a data interchange format for minutiae. It is relevant for systems or components dealing with generating, processing, and storing minutiae data. Representation of fingerprint data using minutiae is a widely used technique in many application areas.

This part of the 19794 standard defines specifics of the extraction of key points (called *minutiae*) from fingerprint ridge patterns. These specifics include a description of the types of minutiae identified, the method used for the placement of minutiae on an image, a definition of the coordinate system used, and the methods used to calculate the angle associated with each minutia.

Information Technology — Biometric data interchange Formats — Part 2: Finger minutiae data

1 Scope

This part of ISO/IEC 19794 specifies a concept and data formats for representation of fingerprints using the fundamental notion of minutiae. The standard is generic, in that it may be applied and used in a wide range of application areas where automated fingerprint recognition is involved. The part of ISO/IEC 19794 contains definitions of relevant terms, a description of how minutiae shall be determined, data formats for containing the data for both general use and for use with cards, and conformance information. Guidelines and values for comparing and decision parameters are provided in an informative Annex.

NOTE Although part 4 of this standard covers both finger and palm image data, this minutiae standard only covers finger minutiae and is not applicable to palms.

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 minutiae record format and Clause 9 for the Finger minutiae on-card biometric comparison 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 Minutiae Record Format and Clause 9 for the Finger Minutiae On-Card Biometric Comparison 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 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 Implementation Conformance Statement (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 Implementation Conformance Statement 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 Implementation Conformance Statement (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 19785-3:2007, Information technology – Common Biometric Exchange Formats Framework (CBEFF) – Part 3: Patron Format Specifications

ISO/IEC 19794-1:—, Information technology – Biometric Data Interchange Formats – Part 1: Framework[1]

ISO/IEC 7816-11:2004, Identification Cards – Integrated circuits cards, Part 11: Personal verification through biometric methods

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
algorithm
sequence of instructions that tell a biometric system how to solve a particular problem

NOTE An algorithm will have a finite number of steps and is typically used by the biometric engine (i.e., the biometric system software) to compute whether a biometric sample and template are the same.

4.4
end user
person who interacts with a biometric system to enrol or have his/her identity checked. Contrast with “User”

4.6
live-scan print
fingerprint image that is produced by scanning or imaging a live finger to generate an image of the friction ridges

4.7
population
set of end-users for the application

4.8
ridge skeleton endpoint
minutia assigned to the location at which a ridge skeleton ends

NOTE A ridge skeleton endpoint is defined as the ending of the skeleton of a ridge.

4.9
template / reference template
data, which represents the biometric measurement of an enrollee, used by a biometric system for comparison against subsequently submitted biometric samples

NOTE This term is not restricted to mean only data used in any particular recognition method, such as template comparison.

4.10
valley bifurcation
point at which a valley splits into two valleys or, alternatively, where two separate valleys combine into one

[1] To be published. Revision of ISO/IEC 19794-1:2006

5 Abbreviated terms

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

BIT	biometric information template
DO	data object
FAR	false acceptance rate
FRR	false rejection rate
RCE	ridge count extraction
RFU	reserved for future use

6 Minutiae extraction

6.1 Purpose

This clause defines the placement of minutiae on the fingerprint. Compatible minutiae extraction is required for interoperability between different finger comparators for the purposes of comparing an individual against a previously collected and stored finger record. Interoperability is based on the definition of the finger minutiae extraction rules, variations of the record format (Clause 7.2), and the on-card biometric comparison format (Clause 7.3) that are common to many finger comparators for acceptable comparing accuracy, while allowing for extended data to be attached for use with equipment that is compatible with it.

6.2 Minutia description

Establishment of a common feature-based representation shall rest on agreement on the fundamental notion for representing a fingerprint. Minutiae are points located at the places in the fingerprint image where friction ridges end or split into two ridges. Describing a fingerprint in terms of the location and direction of these ridge endings and bifurcations provides sufficient information to reliably determine whether two fingerprint records are from the same finger.

The specifications of minutia location and minutia direction described below accomplish this. See Figures 2 through 4 for an illustration of the definitions below.

6.3 Minutia type

6.3.1 General

Each minutia has a “type” associated with it. There are two major types of minutiae: a “ridge skeleton end point” and a “ridge skeleton bifurcation point” or split point. There are other types of “points of interest” in the friction ridges that occur much less frequently and are more difficult to define precisely. More complex types of minutiae are usually a combination of the basic types defined above. Some points are neither a ridge ending nor a bifurcation. This part of ISO/IEC 19794 therefore defines an additional type named “other”, which shall be used for such a case. The “other” minutiae type shall not be used for minutiae that are ridge endings or ridge bifurcations.

Therefore, the following types are distinguished:

- ridge ending
- ridge bifurcation
- other.

A ridge ending may — alternatively — be referred to as a valley bifurcation depending on the method to determine its position (Clause 6.4.3 and 6.4.5). The format type of the biometric information template indicates the use of ridge endings or valley bifurcations.

6.3.2 Unique minutia

A minutia point shall be encoded once. A minutia point is uniquely identified by the location and angle.

6.3.3 Encoding trifurcations

The location at which a ridge splits into three separate ridges is a trifurcation. If it is encoded, it shall be encoded as two bifurcations with identical (x,y) values and different orientation angle values.

6.4 Minutia location

6.4.1 General

The minutia location is represented by its horizontal and vertical position. The minutiae determination strategy considered in this document relies on skeletons derived from a digital fingerprint image. The ridge skeleton is computed by thinning down the ridge area to single pixel wide lines. The valley skeleton is computed by thinning down the valley area to single pixel wide lines. If other methods are applied, they should approximate the skeleton method, i.e. location and angle of the minutia should be equivalent to the skeleton method.

6.4.2 Coordinate system

The coordinate system used to express the minutiae of a fingerprint shall be a Cartesian coordinate system. Points shall be represented by their X and Y coordinates. The origin of the coordinate system shall be the upper left corner of the original image with X increasing to the right and Y increasing downward. Note that this is in agreement with most imaging and image processing use. When viewed on the finger, X increases from right to left as shown in Figure 1. All X and Y values are non-negative.

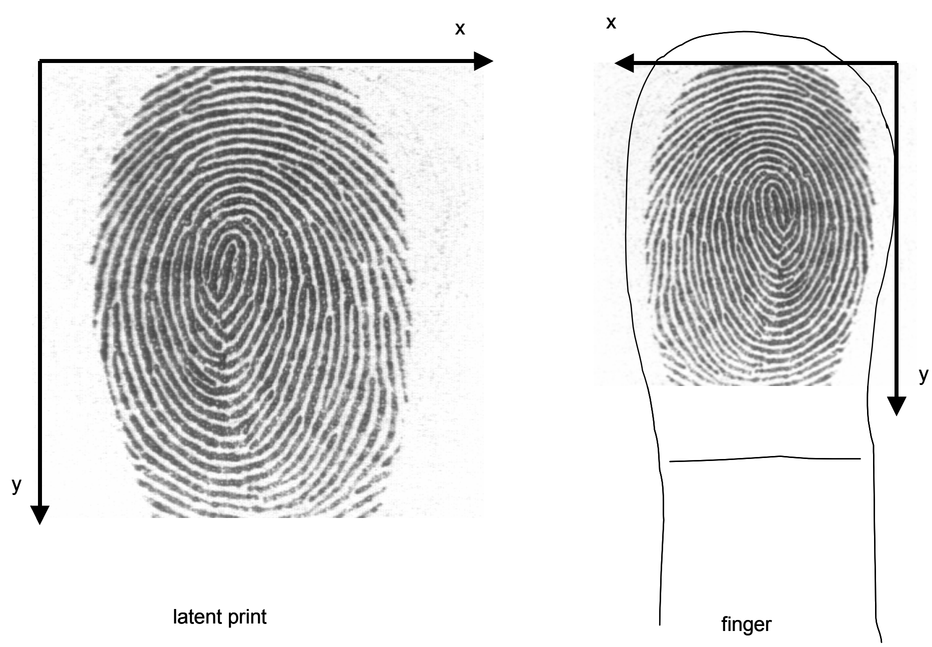

Figure 1 - Coordinate system

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For the finger minutiae record format, clause 7.2, the X and Y coordinates of the minutiae shall be measured in pixel units, with the spatial sampling rate of a pixel given in the “X Spatial sampling rate” and “Y Spatial sampling rate" fields of the record header. The spatial sampling rates are stated separately as described in clauses 8.4.11 and 8.4.12.

For the on-card biometric comparison format, clause 7.3, the X and Y coordinates shall be measured in fixed metrical units of one bit per one tenth of a millimetre or 10^{-1} mm as described in clause 9.2.3.

6.4.3 Minutia placement on a ridge ending (encoded as valley skeleton bifurcation point)

The minutia for a ridge ending shall be defined as the point of forking of the medial skeleton of the valley area immediately in front of the ridge ending. If the valley area were thinned down to a single-pixel-wide skeleton, the point where the three skeletal line intersect is the location of the minutia. In simpler terms, it is the point where the valley bifurcates, or (equivalently) where the three thinned valley lines intersect (see Figure 2).

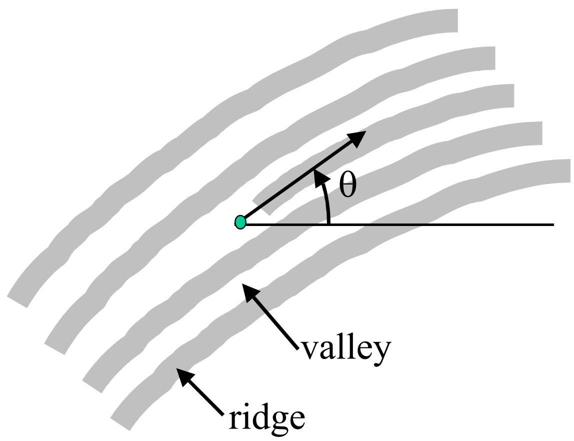


Figure 2 - Location and direction of a ridge ending (encoded as valley skeleton bifurcation point)

6.4.4 Minutia placement on a ridge bifurcation (encoded as a ridge skeleton bifurcation point)

The minutia for a ridge bifurcation shall be defined as the point of forking of the medial skeleton of the ridge. If the ridges were thinned down to a single-pixel-wide skeleton, the point where the three skeletal lines intersect is the location of the minutia. In simpler terms, it is the point where the ridge bifurcates, or (equivalently) where the three skeletal lines of the thinned ridge intersect (see Figure 3).

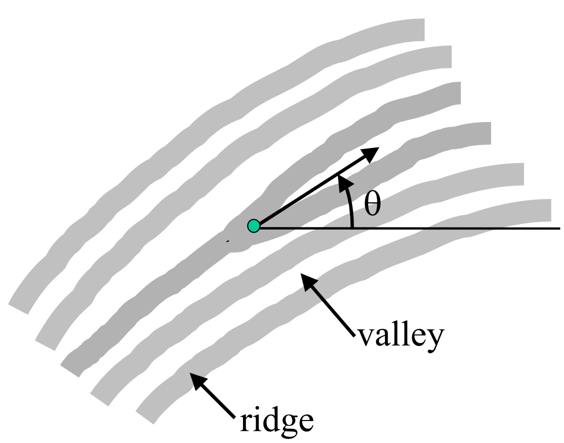


Figure 3 - Location and direction of a ridge bifurcation (encoded as ridge skeleton bifurcation point)

6.4.5 Minutia placement on a ridge skeleton endpoint

The minutia for a ridge skeleton endpoint shall be defined as the center point of the ending ridge. If the ridges in the digital fingerprint image were thinned down to a single-pixel-wide skeleton, the position of the minutia would be the coordinates of the skeleton point with only one neighbour pixel belonging to the skeleton (see Figure 4).

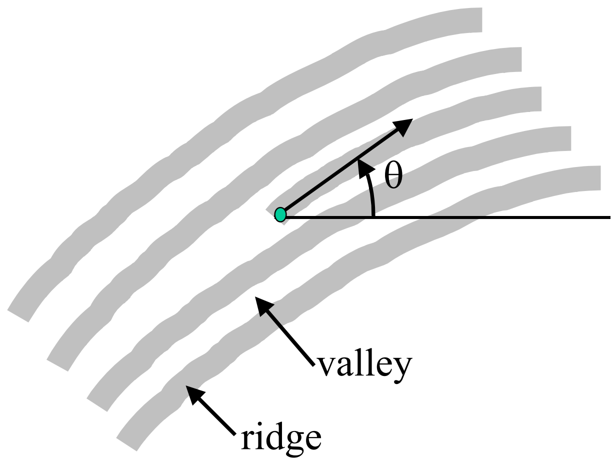


Figure 4 - Location and direction of a ridge skeleton endpoint

6.4.6 Usage of the minutia placement by the record and on-card biometric comparison formats

Depending on the specific algorithms implemented, both the record format and the on-card biometric comparison format use

- Valley skeleton bifurcations or ridge skeleton endpoints for locating minutiae on ridge endings, and
- Ridge skeleton bifurcations for locating minutiae on ridge bifurcations

For on-card biometric comparison, a card will request from the card usage system biometric verification data in the format compliant to its algorithm. The requested format is either implicitly known to the card usage system or can be retrieved in the Biometric Information Template (see ISO/IEC 19785-3 and ISO/IEC 7816-11).

6.5 Minutiae direction

6.5.1 Angle conventions

The minutia angle is measured increasing counter-clockwise starting from the horizontal axis to the right.

In the finger minutiae record format, the angle of a minutia is scaled to fit the granularity of 1.40625 (360/256) degrees per least significant bit as described in clause 8.4.19.1.4.

The angle coding for the on-card biometric comparison formats is scaled to fit the granularity of 5.625 (360/64) degrees per least significant bit as described in clause 9.2.5 .

6.5.2 Minutia direction of a ridge ending (encoded as valley skeleton bifurcation point)

A ridge ending (encoded as valley skeleton bifurcation point) has three arms of valleys meeting in one point. Two valleys enclosing the ridge ending line encompass an acute angle. The direction of a valley bifurcation is defined by the mean direction of their tangents and is measured as the angle the tangent of the ending ridge forms with the horizontal axis to the right (see Figure 2).

6.5.3 Minutia direction of a ridge bifurcation (encoded as ridge skeleton bifurcation point)

A ridge bifurcation (encoded as ridge skeleton bifurcation point) has three arms of ridges meeting in one point. Two ridges enclosing the ending valley encompass an acute angle. The direction of a valley bifurcation is defined by the mean direction of their tangents and is measured as the angle the tangent of the ending valley forms with the horizontal axis to the right (see Figure 3).

6.5.4 Minutia direction of a ridge skeleton end point

The direction of a ridge skeleton endpoint is defined as the angle that the tangent to the ending ridge encompasses with the horizontal axis to the right (see Figure 4).

6.6 Core and delta placement

Core and delta points are designated points of interest in a fingerprint. A fingerprint may have 0, 1 or more cores and 0, 1 or more deltas. The core and delta are defined in ISO/IEC 19794-1. The location of the core and delta positions are defined as follows:

Core position: If there are ridge endings enclosed by the innermost recurving ridgeline, the ending nearest to the maximal curvature of the recurving ridgeline defines the core position. If the core is a u-turn of a ridgeline not enclosing ridge endings, the valley end defines the core position.

Delta position: Three points of divergence are each placed between the two ridges at the location where the ridges begin to diverge; that is, where the ridges that have been parallel or nearly parallel begin to spread apart as they approach the delta. The position of the delta is defined by the spatial mean of these three points. The position is at the point on a ridge at or in front of and nearest the center of the divergence of the ridges that start parallel, diverge, and surround or tend to surround the pattern area of the fingerprint image.

Core and delta point placement is illustrated in Figure 5.

NOTE Cores and deltas represent singularities in the ordinary direction field of the fingerprint image. Hence, angle information of cores and deltas cannot fit smoothly into the direction values of all points in the neighbourhood.

6.7 Encoding of multibyte quantities

All multibyte quantities are represented in Big-Endian format; that is, the more significant bytes of any multi-byte quantity are stored at lower addresses in memory than (and are transmitted before) less significant bytes. All numeric values are fixed-length integer quantities, and are unsigned quantities.

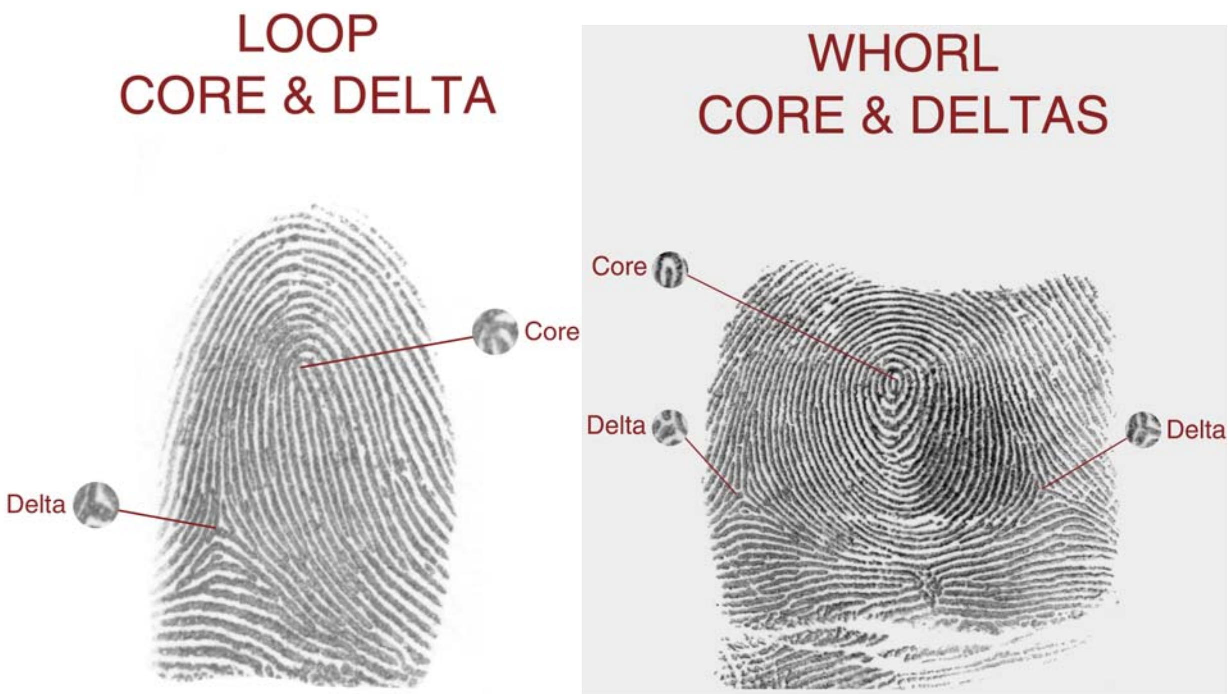


Figure 5 - Example core and delta placement

7 Finger minutiae format types

7.1 Overview

This part of 19794 defines two format types for minutiae encoding. These format types have been derived from those listed in Version 2 of this part of ISO/IEC 19794 (ISO/IEC 19794-2:2005). The first record format is designed for general storage, data interchange, or card based system. The second is an on-card biometric comparison format intended for the comparison-on-card application as described in ISO/IEC 24787. Table 1 provides a tabular illustration of the two format types and the options available for each type.

7.2 Record format

This record format (Clause 8) requires the use of a general header for each finger record and a representation header for each representation of the finger. This format is also designed to accommodate ridge count data, core and delta data, zonal quality data, or vendor-defined extended data. Within the representation header parameters shall be set to indicate whether five or six bytes are needed for each minutiae (the latter includes a 1 byte quality field for each minutia). A second field in the representation header is used to differentiate between ridge ending minutiae determined by ridge skeleton end points, and those determined using valley bifurcations. A third field encodes the vendor of the minutiae extraction algorithm. The fourth field is a vendor-assigned identification of the feature extraction algorithm used by the vendor.

7.3 On-card comparison format

This on-card biometric comparison format (Clause 9) precludes the use of a general or representation header. Unlike the record format, the on-card biometric comparison format does not have a header and only has provision for a single representation record of the finger. This corresponds to the compact-size card format types that existed in ISO/IEC 19794-2:2005, which require three bytes to describe each minutiae. This format locates ridge endings using either the ridge skeleton end-points or valley bifurcation points. As with the record

Table 1 - Format type options

Format		Extended data (Option)	Ridge ending	Ridge bifurcation	minutiae size (per minutiae)
Finger Minutiae Record Format	Finger Minutia Qualified Pixel Record Format	Supported	Ridge valley bifurcation	Ridge bifurcation	6 byte
			Ridge Skeleton end point		
	Finger Minutia Pixel Record Format	Supported	Ridge valley bifurcation	Ridge bifurcation	5 byte
			Ridge Skeleton end point		
Finger Minutiae On-Card Biometric Comparison Format		Supported with DOs	Ridge valley bifurcation	Ridge bifurcation	3 byte
			Ridge skeleton end point	Ridge bifurcation	3 byte

format, bifurcations are located using ridge skeleton bifurcation points. Whether the ridge endings are represented by ridge skeleton end-points or valley skeleton bifurcation points shall be indicated by different CBEFF BDB format type identifiers (see clause 10).

8 Finger minutiae record format

8.1 Introduction

The finger minutiae record format shall be used to achieve interoperability between finger minutiae extraction and comparison subsystems. The record format requires a general header. The minutiae data are represented by different variations and may contain extended data in addition to the basic data. The formats differ in two respects: the size of the encoded minutia, and whether ridge endings are determined by valley skeleton bifurcation or ridge skeleton end points. With the exception of the Format Identifier and the Version number for the standard, which are null-terminated ASCII character strings, all data is represented in binary format. There are no record separators or field tags; fields are parsed by byte count.

8.2 Record organization

The organization of the record is as follows:

- A single fixed-length (15-byte) general header containing information about the overall record, including the number of finger representations and the overall record length in bytes;

- A single finger record for each finger representation, consisting of:

    - A variable-length finger minutiae representation header containing information about the data for a single finger representation, including the number of minutiae;

      Note 1 For each quality block of information recorded the length will be increased by 5 bytes

Note 2 When capture device certification information is present, one byte for the count of certifications is required plus an additional 3 bytes for each specific certification

- A variable-length finger minutiae representation body containing
  - A series of fixed-length (6-byte, or 5-byte) minutia descriptions, including the position, type, and angle (quality of the minutia is also included for the 6-byte record format);

    and

  - One required extended data block for each finger representation containing zero or more extended data areas describing optional or vendor specific information.

8.3 General header

There shall be one and only one general header for the minutiae record. Table 2 contains a summary of the general record header fields.

Table 2 – General header

	Field	**Size**	**Valid Values**	**Notes**
One per Record	Format Identifier	4 bytes	$464D5200_{Hex}$ (‘F’ ‘M’ ‘R’ 00_{Hex})	“FMR ” – finger minutiae record
	Version Number	4 bytes	30333000_{Hex} (‘0’ ‘3’ ‘0’ 00_{Hex})	Version = 030
	Length of record	4 bytes	36_{Hex} to $FFFFFFFF_{Hex}$	Minimum length is 15 for the general header plus 39 for each representation (1 minutiae) = 54 to 2^{32}-1
	Number of Finger Representations	2 bytes	0001_{Hex} to 0160_{Hex}	(10 fingers + 1 unknown + 11 multiple finger combinations) times 16 = 352
	Device Certification Block Flag	1 byte	00_{Hex} or 01_{Hex}	Indicates the presence of any device certification blocks within the representation headers

8.3.1 Format identifier

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

8.3.2 Version number

The number for the version of this part of ISO/IEC 19794 used for constructing the finger minutiae BDIR shall be placed in four bytes. This version number shall consist of three ASCII numerals followed by a zero byte as a NULL 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 “030” – Version 3 revision 0.

8.3.3 Length of record

The length (in bytes) of the entire finger minutiae 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.

8.3.4 Number of finger representations

The total number of representations 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, this number will be greater than the number of fingers.

8.3.5 Device certification block flag

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

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

8.4 Finger minutiae representation format

8.4.1 Finger minutiae representation header

A finger minutiae representation header shall precede each representation of finger minutiae data providing information for that finger representation. There shall be one finger representation header for each finger representation contained in the finger minutiae record. The finger representation header will occupy a minimum of 35 bytes as described below. As the number of finger image quality blocks, capture device certification blocks, and extended data areas are added, the length of the finger header will increase. Table 3 contains a summary of the fields for the finger representation format. Table 4 describes the contents of extended data areas. These two tables list the header fields, and all fields that may occur in a representation including the finger minutiae data fields and extended data fields.

NOTE It is permissible to have multiple finger representations of the same finger in the same finger minutia record provided that each representation's data is derived from a unique capture of the same finger.

8.4.2 Representation length

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

8.4.3 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.

8.4.4 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. A value of 00_{Hex} indicates unknown or unspecified technology. See Table 5 for the list of possible values.

8.4.5 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.

Table 3 – Finger minutiae representation format

Field	Size	Valid Values	Notes
Representation length	4 bytes	27_{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 5 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.
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 block	1 to 1,276 bytes (1 to 1 + (255 * 5))	See ISO/IEC 19794-1	A quality block shall consist of a length field followed by zero or more quality sub-blocks. The length field shall consist of one byte. It shall represent the number of quality sub-blocks as an unsigned integer. Each quality sub-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 block	1 to 766 bytes (1 to 1 + (255 * 3))	See ISO/IEC 19794-1	The certification block only exists if the certification flag in the general header has a value of 1. A certification block shall consist of a length field followed by zero or more certification sub-blocks. The length field shall consist of one byte. It shall represent the number of unique certification sub-blocks as an unsigned integer. Each certification sub-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 6 for the list of certification scheme identifiers.
Finger position	1 byte	0 to 10; 13 to 15; 40 to 50	See Table 7
Representation number	1 byte	0 to 15	Up to 16 representations for each finger
Image spatial sampling rate (horiz)	2 bytes	0062_{Hex} to $FFFF_{Hex}$	In pixels/cm (minimum of 98 pp/cm)
Image spatial sampling rate (vert)	2 bytes	0062_{Hex} to $FFFF_{Hex}$	In pixels/cm (minimum of 98 pp/cm)
Impression type	1 byte	0 to 9; 24; 28 to 29	See Table 8
Size of scanned image in X-Dir	2 bytes	0000_{Hex} to $3FFF_{Hex}$	In pixels
Size of Scanned image in Y-dir	2 bytes	0000_{Hex} to $3FFF_{Hex}$	In pixels
Minutiae field length	4 bits	5, 6	6 byte format includes a quality byte
Ridge ending type	4 bits	0,1	0 –intersection of valley bifurcation lines 1 – ridge skeleton endpoints
Number of minutiae	1 byte	1 to 255	

One per minutia	Minutia type	2 bits	0 Hex to 3 Hex	00 other 01 ridge ending 10 ridge bifurcation 11 reserved by SC 37 for future use
	Minutia X	14 bits	0000 Hex to 3FFF Hex	Expressed in pixels
	Reserved by SC 37 for future use	2 bits	0 Hex	
	Minutia Y	14 bits	0000 Hex to 3FFF Hex	Expressed in pixels
	Angle Ø	1 byte	0 to 255	Resolution is 1.40625 degrees
	Minutia Quality	0 or 1 byte	0 to 100; 254; 255	Minutia quality field does not exist for the 5-byte format, 254 means quality score is not reported and 255 indicates failure to compute quality.
Extended data block length		2 bytes	0000 Hex 0004 Hex to FFFF Hex	0000Hex indicates that there is no extended data
0+	Extended data area type Code	2 bytes	0000 Hex to FFFF Hex	Only if Extended data block length ≠0 See Table 11
	Extended data area length	2 bytes	0004 Hex to FFFF Hex	Only if Extended data block length ≠0. If this field is present, its value includes the count of the length and type identification fields (four bytes total).
	Extended data	00 Hex to FFFB Hex bytes	See clause 8.5.1.4	Only if Extended data block length ≠0 The minimum size in bytes of the Extended Data is 00 Hex because clause 8.5.1 provides no specific guidance for vendor-defined extended data. The maximum size in bytes of the Extended Data is FFFB Hex, which is FFFF Hex minus the 2-byte length of the Extended Data Area Type Code field and the 2-byte length of the Extended Data Area Length field.

Table 4 - Extended data areas

Each extended data area may contain vendor-specific data, or one or more of the following (in any order)					
		Field	**Size**	**Valid Values**	**Notes**
Ridge count data	0+	Ridge count extraction method	1 byte	0 to 2	Non-specific, 4-neighbour quadrants, or 8-neighbour octants
		Ridge count data – idx #1	1 byte	1 to 255	Starting minutia
		Ridge count data – idx #2	1 byte	0 to 255	Neighbouring minutia
		Count of ridges	1 byte	0 to 255	Intersecting ridges
Delta and Core Data		Reserved	4 bits	0_{Hex}	Reserved by SC 37 for future use
		Number of cores	4 bits	0 to 15	
	0+	Core information type	2 bits	00, 01	01 - 1 core angle present
		X location	14 bits	0000_{Hex} to $3FFF_{Hex}$	
		Reserved	2 bits	0_{Hex}	Reserved by SC 37 for future use
		Y location	14 bits	0000_{Hex} to $3FFF_{Hex}$	
		Core angle	1 byte	00_{Hex} to FF_{Hex}	Angle present if Core information type = ‘01’
		Reserved	4 bits	0_{Hex}	Reserved by SC 37 for future use
		Number of deltas	4 bits	0 to 15	
	0+	Delta information type	2 bits	00, 01	01 – 3 delta angles present
		X location	14 bits	0000_{Hex} to $3FFF_{Hex}$	
		Reserved	2 bits	0_{Hex}	Reserved by SC 37 for future use
		Y location	14 bits	0000_{Hex} to $3FFF_{Hex}$	
		Delta angle # 1	1 byte	00_{Hex} to FF_{Hex}	These angles present if Delta information type = ‘01’
		Delta angle # 2	1 byte	00_{Hex} to FF_{Hex}	
		Delta angle # 3	1 byte	00_{Hex} to FF_{Hex}	
Zonal quality data		Zonal quality vendor ID	2 bytes	0000_{Hex} to $FFFF_{Hex}$	ID registered with IBIA
		Zonal quality algorithm	2 bytes	0000_{Hex} to $FFFF_{Hex}$	Assigned by vendor
		Cell width	1 byte	1 to 255	Number of pixels
		Cell height	1 byte	1 to 255	Number of pixels
		Cell information bit depth	1 byte	1 to 8	
		Cell quality data	*Cell Data Length*	0 to 2^{depth} -1	

8.4.6 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.

Table 5 - Capture device technology ID

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

8.4.7 Finger image quality

8.4.7.1 General

The quality information of the overall finger image data, if present, shall be recorded in one or more five-byte blocks when the number of quality blocks field is greater than 0. Each of these blocks shall pertain to a specific quality/vendor/algorithm evaluation. Figure 6 illustrates the placement and recording of multiple quality blocks.

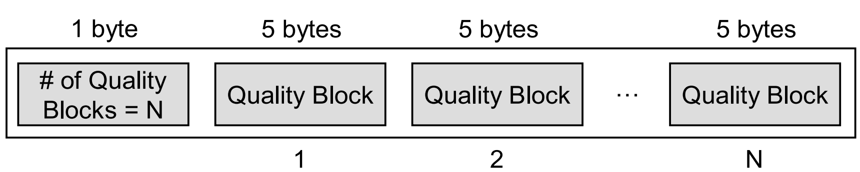


Figure 6 - Image quality layout

8.4.7.2 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.

8.4.7.3 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.

8.4.7.4 Quality 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).

8.4.7.5 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 0000_{Hex} to $FFFF_{Hex}$. Multiple quality scores calculated by the same algorithm (same vendor ID and algorithm ID) shall not be present in a single representation.

8.4.8 Capture device certifications

8.4.8.1 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 block shall consist of a length field followed by zero or more 3-byte certification sub-blocks. Each certification sub-block shall consist of a certification authority identifier, and a certification scheme identifier.

If the device certification block 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 minutiae record.

8.4.8.2 Number of certifications

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

8.4.8.3 Certification authority identifier

The first two bytes of each sub-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 capture device quality certification scheme.

8.4.8.4 Certification scheme identifier

This last byte of the sub-block shall identify a certification scheme used to certify the capture device. A list of current certification scheme identifiers is contained in Table 6.

8.4.9 Finger position

The finger position shall be recorded in one byte. The codes for this byte shall be chosen from Table 7 which lists single finger and multiple finger combinations.

NOTE The capability to compare minutiae from un-segmented fingers (i.e. finger-position codes 13 and above) has not been demonstrated, and will require dedicated research and development.

Table 6 - Identifiers for certification schemes specified in the annexes

Certification scheme Identifier	Annex
00_{Hex}	Reserved by SC 37 for future use
01_{Hex}	E.1 — Image quality specification for AFIS systems
02_{Hex}	E.2 — Image quality specification for personal verification
03_{Hex}	E.3 — Requirements and test procedures for optical fingerprint scanners
04_{Hex} to FF_{Hex}	Reserved by SC 37 for future use

8.4.10 Representation number

This one byte field shall contain the specific image representation number associated with the finger. If there is more than one finger minutiae representation from the same finger in a finger minutiae record, each minutiae record shall have a unique representation number. The combination of finger location and representation number shall uniquely identify a particular minutiae representation within a minutiae record. Multiple finger minutiae representations from the same finger shall be numbered with increasing representation numbers, beginning with zero. Where only one finger minutiae record is taken from each finger, this field shall be set to 0.

8.4.11 Image spatial sampling rate (horizontal)

The horizontal spatial sampling rate of the minutiae coordinate system shall be recorded in two bytes having the units of pixels per centimeter. The value of the X spatial sampling rate shall not be less than 98.45 pixels per centimeter (250 pixels per inch).

8.4.12 Image spatial sampling rate (vertical)

The vertical spatial sampling rate of the minutiae coordinate system shall be recorded in two bytes having the units of pixels per centimeter. The value of the Y spatial sampling rate shall not be less than 98.45 pixels per centimeter (250 pixels per inch).

8.4.13 Impression type

The impression type of the finger images from which the minutiae data was derived shall be recorded in this one byte field. The codes for this byte are shown in Table 8 - Finger impression codes. These codes are compatible with Table 8 - Finger impression codes of the ANSI/NIST-ITL 1-2007, “Data Format for the Interchange of Fingerprint Information”.

8.4.14 Size of scanned image in X-direction

This two-byte binary field shall be used to specify the number of pixels contained on a single horizontal line of the transmitted image. The range of allowed values is 0000_{Hex} to $3FFF_{Hex}$ for compatibility with the Minutia, Core, and Delta Position fields.

8.4.15 Size of scanned image in Y-direction

This two-byte binary field shall be used to specify the number of horizontal lines contained in the transmitted image. The range of allowed values is 0000_{Hex} to $3FFF_{Hex}$ for compatibility with the Minutia, Core, and Delta Position fields.

Table 7 - Finger position codes

Finger position	Code
Unknown finger	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
Left thumb and right thumb	15
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
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

Table 8 - Finger 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	Vertical roll
10 to 23	Reserved by SC 37 for future use
24	Live-scan optical contactless plain
25 to 27	Reserved by SC 37 for future use
28	Other
29	Unknown

8.4.16 Minutia field length

The number of bytes required to describe each minutia shall be recorded in four high-order (most significant) bits of the byte. The contents of this field shall be either 6 to indicate a 6-byte minutia format (including a 1-

byte quality field) or a 5 to indicate a 5-byte minutia format (with no quality information). The low-order four bits of the byte shall contain the “Ridge Ending Type”.

8.4.17 Ridge ending type

The method used to determine the location of a ridge ending shall be recorded in four low-order (least significant) bits of the byte. A value of 0 shall indicate that the minutia was located using the intersection of three valleys. A value of 1 shall indicate that the minutia was located using ridge skeleton endpoints. The high-order four bits of the byte shall contain the length of minutiae field.

8.4.18 Number of minutiae

The number of minutiae extracted and encoded for the finger shall be recorded in this one byte.

8.4.19 Finger minutiae data

The finger minutiae data for a single finger shall be recorded in blocks of six or five bytes per minutia. This is dependent on the minutiae field length as encoded in the above in clause 8.4.16. The method used to locate ridge endings is independent of the number of bytes required to represent a minutia. The order of the minutiae is not specified.

8.4.19.1 Qualified finger minutia pixel record format

8.4.19.1.1 Overview

Using the qualified finger minutia pixel record format, six bytes are needed to encode each minutia. Table 9 illustrates the layout of the bits and bytes for minutiae type, location, angle, and quality descriptors for the 6-byte minutiae format.

Table 9 – Qualified finger minutia pixel record format

type t	x-coordinate	Reserved	y-coordinate	angle θ	Quality
2 bits	14 bits	2 bits	14 bits	1 byte	1 byte

8.4.19.1.2 Minutia type

The type of minutia (type t) will be recorded in the first two bits of the upper byte of the X coordinate. The bits “00” will represent a minutia of “other” type, “01” will represent a ridge ending and “10” will represent a ridge bifurcation. Type “11” is reserved by SC 37 for future use. Minutia type “other” shall not be used for minutiae that are either ridge endings or ridge bifurcations. Ridge endings may either be encoded as valley skeleton bifurcation points or ridge skeleton end points.

8.4.19.1.3 Minutia position

The X coordinate of the minutia shall be recorded in the rest of the first two bytes (fourteen bits). The Y coordinate shall be placed in the lower fourteen bits of the following two bytes. The upper two bits are reserved by SC 37 for future use and shall be set to ‘00’. The coordinates shall be expressed in pixels at the spatial sampling rate indicated in the representation header. Position information shall be present for each minutia, regardless of type, although position for minutiae of type “other” is vendor-defined.

8.4.19.1.4 Minutia angle

The angle of the minutia shall be recorded in one byte in units of 1.40625 (360/256) degrees. The value shall range from 0 to 255, inclusive. For example, an angle value of 16 represents 22.5 degrees. Note that angle information shall be present for each minutia, regardless of type, although angle for minutiae of type “other” is vendor defined.

8.4.19.1.5 Minutia quality

Minutia quality is the confidence that the minutia is a true minutia. The quality value shall range from 100 as a maximum to 0 as a minimum. A value of 254 indicates the quality was not reported and a value of 255 indicates failure to acquire a quality score.

8.4.19.2 Finger minutia pixel record format

8.4.19.2.1 Overview

Using the minutia pixel record format, only five bytes are needed to encode each minutia. Table 10 illustrates the layout of the bits and bytes for minutiae type, location, and angle descriptors.

Table 10 – Finger minutia pixel record format

type t	x-coordinate	reserved	y-coordinate	angle θ
2 bits	14 bits	2 bits	14 bits	1 byte

8.4.19.2.2 Minutia type, position, and angle

The 5-byte minutia non-qualified pixel format is the same as the 6-byte minutia qualified pixel format without the quality byte. The same field descriptions as in the 6-byte minutia qualified pixel format are applicable to this format also.

8.5 Extended data

The extended data section of the finger minutiae record format is provided for the storage of additional data that may be used by the comparison equipment. The size of this section shall be kept as small as possible, augmenting the data stored in the standard minutiae section. The extended data for each finger representation shall immediately follow the standard minutiae data for that finger representation and shall begin with the Extended Data Block Length field. More than one extended data area may be present for each finger and the extended data block length field will be the summation of the lengths of each extended data segment. The data block length is used as a signal for the existence of the extended data while the individual extended data length fields are used as indices to parse the extended data. Note that the extended data area shall not be used alone, without the standard portion of the minutiae record.

While the extended data area allows for inclusion of vendor-defined data within the minutiae format, this is not intended to allow for alternate representations of data that can be represented in an open manner as defined in this part of ISO/IEC 19794. In particular, ridge count data, core and delta data or zonal quality information shall not be represented in vendor-defined manner to the exclusion of the publicly defined formats in this part of ISO/IEC 19794. Additional ridge count, core and delta or zonal quality information may be placed in a vendor-defined extended data area if the standard fields defined below are also populated. The intention of this part of ISO/IEC 19794 is to provide interoperability.

8.5.1 Common extended data fields

8.5.1.1 Extended data block length

All finger records shall contain the extended data block length. This field will signify the existence of extended data. A value of all zeros (0000_{Hex}) will indicate that there is no extended data and that the record will end or continue with the next finger representation. A nonzero value will indicate the length of all extended data starting with the next byte. The block length will then be followed by the type identification code (8.5.1.2), length of data field (8.5.1.3) and the data area (8.5.1.4).

8.5.1.2 Extended data area type code

The type identification code shall be recorded in two bytes, and shall distinguish the format of the extended data area. A value of zero in both bytes is a reserved by SC 37 for future use 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. 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 type identification codes. If the Extended Data Block Length (8.5.1.1) for the finger representation is zero, indicating no extended data, this field shall not be present.

Table 11 - Extended data area type codes

First byte	Second byte	Identification
00_{Hex}	00_{Hex}	Reserved by SC37 for future use
00_{Hex}	01_{Hex}	ridge count data (8.5.2)
00_{Hex}	02_{Hex}	core and delta data (8.5.3)
00_{Hex}	03_{Hex}	zonal quality data (8.5.4)
00_{Hex}	04_{Hex} to FF_{Hex}	Reserved by SC37 for future use
01_{Hex} to FF_{Hex}	00_{Hex}	Reserved by SC37 for future use
01_{Hex} to FF_{Hex}	01_{Hex} to FF_{Hex}	Vendor specific extended data

8.5.1.3 Extended data area length

The length of the extended data section shall be recorded in two bytes. This value is used to skip to the next extended data if the comparator cannot decode and use this data. If the Extended Data Block Length (8.5.1.1) for the finger representation is zero, indicating no extended data, this field shall not be present. If the field is present, this length field includes the count of the length and type identification fields (four bytes total).

8.5.1.4 Data section

The data field of the extended data is defined by the equipment that is generating the finger minutiae record, or by common extended data formats contained in this part of ISO/IEC 19794; see clauses 8.5.2, 8.5.3, and 8.5.4. If the Extended Data Block Length (8.5.1.1) for the finger representation is zero, indicating no extended data, this field shall not be present.

8.5.2 Ridge count data format

If the extended data area type code is 0001_{Hex}, the extended data area contains ridge count information. The minimum value for the Extended Data Area Length field of a Ridge Count Extended Data area is 5 bytes. This consists of 2 bytes for type, 2 bytes for length, and one byte to identify a ridge count extraction method.This format provides optional information about the number of fingerprint ridges between pairs of minutiae. Each ridge count is associated with a pair of minutiae contained in the minutiae data area defined in clause 8.4.19. No ridge information may be contained that is associated with minutiae not included in the corresponding minutiae area. Ridge counts shall not include the ridges represented by either of the associated minutiae. Refer to Figure 7 for clarification; the ridge count between minutiae A and B is 1, while the ridge count between minutiae B and C is 2.

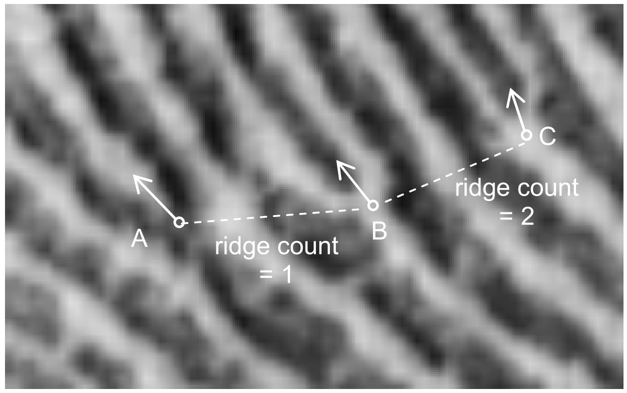


Figure 7 - Example ridge count data

8.5.2.1 Ridge count extraction method

The ridge count data area shall begin with a single byte indicating the ridge count extraction method. Ridge counts associated with a particular central minutia (a minutiae used as the reference to generate the subsequent ridge counts relevant for the ridge count extraction method) are frequently extracted in one of two ways: by extracting the ridge count to the nearest neighbouring minutia in each of four angular regions (or quadrants), or by extracting the ridge count to the nearest neighbouring minutia in each of eight angular regions (or octants). The ridge count extraction method field shall indicate the extraction method used, as shown in Table 12. It is not necessary for all minutiae in the minutiae data area to have ridge count data associated with each minutia.

If either of these specific extraction methods are used, the ridge counts shall be listed in the following way:

- all ridge counts for a particular central minutia shall be listed together;
- the central minutia shall be the first minutia referenced in the three-byte ridge count data;
- the listing of the central minutiae of each 3-byte data block shall be ordered and the order of the listing of neighbouring minutiae for each central minutia are not defined by the standard.

Table 12 - Ridge count extraction method codes

RCE method field value	Extraction method	Comments
00_{Hex}	Non-specific	No assumption shall be made about the method used to extract ridge counts, nor their order in the record; in particular, the counts may not be between nearest-neighbour minutiae
01_{Hex}	Four-neighbour (quadrants)	For each central minutia used, ridge count data was extracted to the nearest neighbouring minutia in four quadrants, and ridge counts for each central minutia are listed together
02_{Hex}	Eight-neighbour (octants)	For each central minutia used, ridge count data was extracted to the nearest neighbouring minutia in eight octants, and ridge counts for each central minutia are listed together

8.5.2.1.1 Eight-neighbour ridge count extraction method

Ridge count information for the eight-neighbour ridge count extraction method shall be extracted as follows

- Each central minutia used shall be assigned its own unique “neighbourhood” consisting of eight octants (angular sectors of 45 degrees) of a (theoretical) circle centered on the location of the minutia. The octants shall be numbered counterclockwise from zero to seven with octant number zero locally center aligned with the direction of the minutiae. Figure 8 - Eight-minutiae neighbourhood provides an example of a central minutiae whose "tail" is aligned toward the "South-Southwest" direction. The zero octant spans the arc of 22.5 degrees on either side of "South-Southwest". The "tail" bisects the zero octant.

- For each octant, a ridge count is produced by counting the number of ridges crossed by a (theoretical) straight line *between* the central minutia and the minutia *nearest* to it (i.e. its "nearest neighbour") in that octant, *including* the ridge on which the nearest neighbouring minutia lies (i.e. the number of intervening ridges plus one).

Note that the ridge(s) defining the minutia are considered part of the minutia. For example, if the central minutia is a ridge ending, and if the straight line passing from it to a nearest neighbouring minutia in another octant crosses over the ridge the central minutia is on, that crossover does not increment the count.

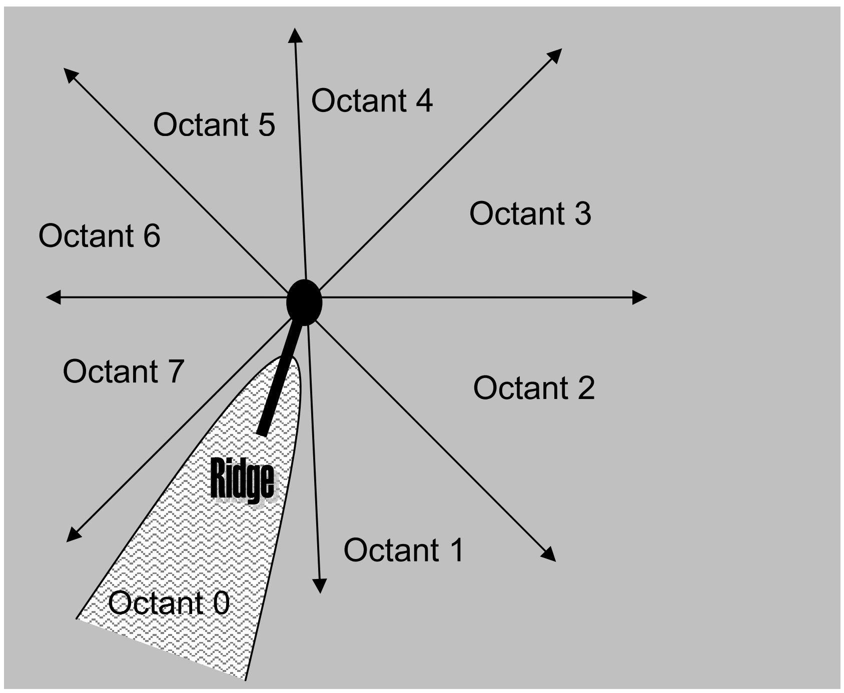


Figure 8 - Eight-minutiae neighbourhood

Note also that due to the curving of ridges, the straight line between a minutia and its neighbour might cross a ridge twice (or more). In this case the same ridge shall not be counted more than once, unless the straight line which connects the central minutia to its nearest neighbour minutia passes through at least the center of one valley before entering back into the same ridge. A ridge shall not be counted unless the straight line passes at least to the center of the ridge thickness.

8.5.2.1.2 Four- neighbour ridge count extraction method

Ridge count information for the four-neighbour ridge count extraction method shall be extracted as follows.

- Each central minutia used shall be assigned its own unique "neighbourhood" consisting of four quadrants (angular sectors of 90 degrees) of a (theoretical) circle centered on the location of the minutia. The quadrants shall be numbered counterclockwise from one to four. The central minutia shall be locally aligned on the 'Y' axis between quadrant 3 and 4. Figure 9 provides an example of a central minutiae whose "tail" is aligned toward the "South" direction. The "tail" bisects the two lower quadrants.

- For each quadrant, a ridge count is produced by counting the number of ridges crossed by a (theoretical) straight line *between* the central minutia and the minutia *nearest* to it (i.e. its "nearest neighbour") in that quadrant, *including* the ridge on which the nearest neighbour minutia lies (i.e. the number of intervening ridges plus one).

Note that the ridge(s) defining the minutia are considered part of the minutia. For example, if the centeral minutia is a ridge ending, and if the straight line passes through one of the ridge segments forming the ridge ending, the latter is not counted separate from the minutia and does not increment the count.

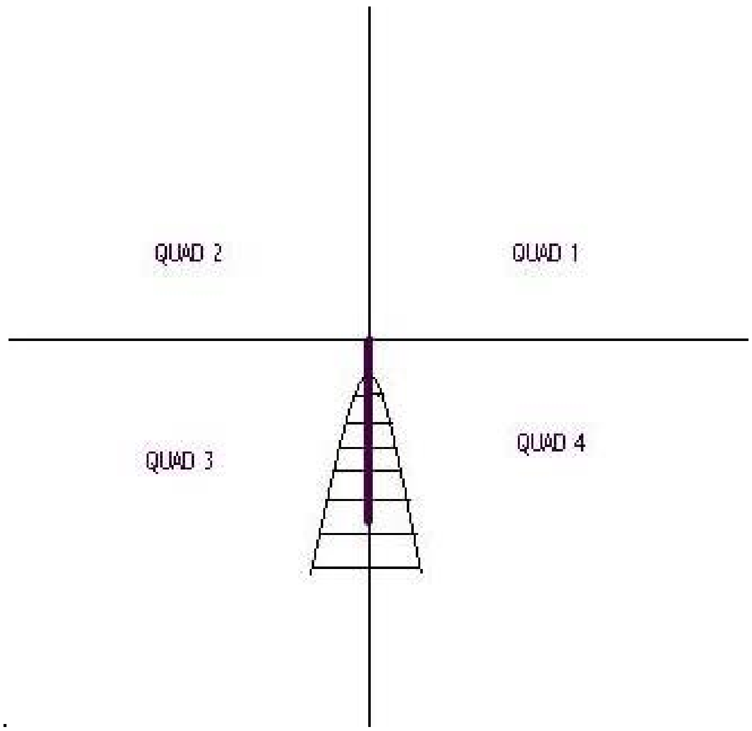


Figure 9 - Four-minutiae neighbourhood

Note also that due to the curving of ridges, the straight line between a minutia and its neighbour might cross a ridge twice (or more). In this case the same ridge shall not be counted more than once, unless the straight line which connects the central minutia to its nearest neighbour minutia passes through at least the center of one valley before entering back into the same ridge. A ridge shall not be counted unless the straight line passes at least to the center of the ridge thickness.

8.5.2.2 Ridge Count Data

The ridge count data shall be represented by a list of three-byte elements. The first and second bytes are an index number, indicating which minutiae in the corresponding minutia area are being considered. The third byte is a count of the ridges intersected by a direct line between these two minutiae.

If a given quadrant or octant has no neighbouring minutiae in it, a ridge count data three-byte element shall be recorded with the first minutia index field set to the central minutia index number, the second minutia index field set to 255 and the ridge count field set to 255. For each central minutia, there shall always be four ridge counts recorded for the quadrant method and eight ridge counts recorded for the octant method.

The ridge count data shall be listed in increasing order of the index numbers, as shown in Table 13. Since the minutiae are not listed in any specified geometric order, no assumption shall be made about the geometric relationships of the various ridge count items.

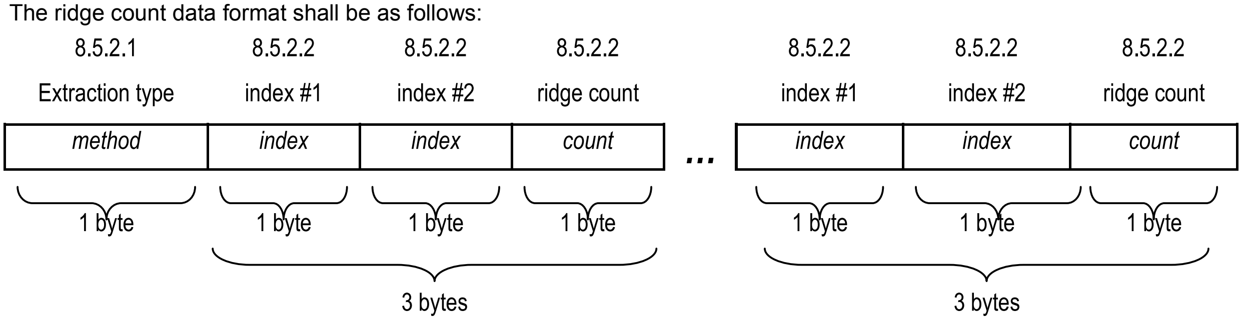
Table 13 - Example ridge count data

(non-specific extraction method, RCE method = 00_{Hex})

Minutia index #1	Minutia index #2	Ridge count
01_{Hex}	02_{Hex}	05_{Hex}
01_{Hex}	06_{Hex}	09_{Hex}
01_{Hex}	07_{Hex}	02_{Hex}
02_{Hex}	04_{Hex}	13_{Hex}
02_{Hex}	09_{Hex}	$0D_{Hex}$
05_{Hex}	03_{Hex}	03_{Hex}
09_{Hex}	15_{Hex}	08_{Hex}

8.5.2.3 Ridge count format summary

The ridge count data format shall be as follows:



8.5.3 Core and delta data format

8.5.3.1 General

If the extended data area type code is 0002_{Hex}, the extended data area contains core and delta information. This format is provided to contain optional information about the placement and characteristics of the cores and deltas on the original fingerprint image. Core and delta points are determined by the overall pattern of ridges in the fingerprint. There may be zero or more core points and zero or more delta points for any fingerprint. Core and delta points may or may not include angular information. The required data entries for core and delta point placement, as described in clause 6.6, are defined in the following subclauses.

NOTE The capability to precisely and consistently compute core and delta orientation has not been demonstrated, and will require dedicated research and development to ensure interoperability.

8.5.3.2 Core information

8.5.3.2.1 Number of cores

The number of core points represented shall be recorded in the least significant four bits of this byte. Valid values are from 0 to 15. The high-order (most significant) 4 bits are reserved by SC 37 for future use and shall be set to 0

8.5.3.2.2 Core information type

The core information type shall be recorded in the first two bits of the upper byte of the X coordinate of the core position. The bits “01” will indicate that the core has angular information while “00” will indicate that no angular information is relevant for the core type. If this field is “00”, then the angle fields shall not be present for the cores.

8.5.3.2.3 Core position

The X coordinate of the core shall be recorded in the lower fourteen bits of the first two bytes of each core description. The Y coordinate shall be placed in the lower fourteen bits of the following two bytes. The high-order (most significant) 2 bits of the Y coordinate are reserved by SC 37 for future use and shall be set to 0. For both the 5-byte and 6-byte minutiae formats, the coordinates shall be expressed in pixels at the spatial sampling rate indicated in the representation header.

8.5.3.2.4 Core angle

The angle of the core shall be recorded in one byte in units of 1.40625 (360/256) degrees. The core angle is measured increasing counter-clockwise starting from the horizontal axis to the right. The value shall be a non-negative value between 0 and 255, inclusive. For example, an angle value of 16 represents 22.5 degrees. If the core information type is zero (Clause 8.5.3.2.2) then this field shall not be present.

8.5.3.3 Delta information

8.5.3.3.1 Number of deltas

The number of delta points represented shall be recorded in the least significant four bits of this byte. Valid values are from 0 to 15. The high-order (most significant) 4 bits are reserved by SC 37 for future use and shall be set to 0.

8.5.3.3.2 Delta information type

The delta information type shall be recorded in the first two bits of the upper byte of the X coordinate of the delta position. The bits “01” will indicate that the delta has angular information while “00” will indicate that no angular information is relevant for the delta type. If this field is “00”, then the angle fields shall not be present for the deltas.

8.5.3.3.3 Delta position

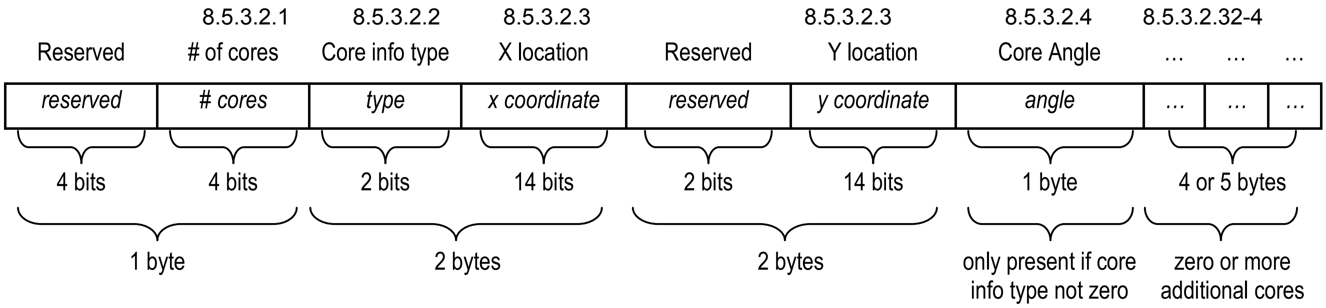
The X coordinate of the delta shall be recorded in the lower fourteen bits of the first two bytes of each delta description. The Y coordinate shall be placed in the lower fourteen bits of the following two bytes. The high-order (most significant) 2 bits the Y coordinate are reserved by SC 37 for future use and shall be set to 0. For both the 5-byte and 6-byte minutiae formats, the coordinates shall be expressed in pixels at the spatial sampling rate indicated in the representation header.

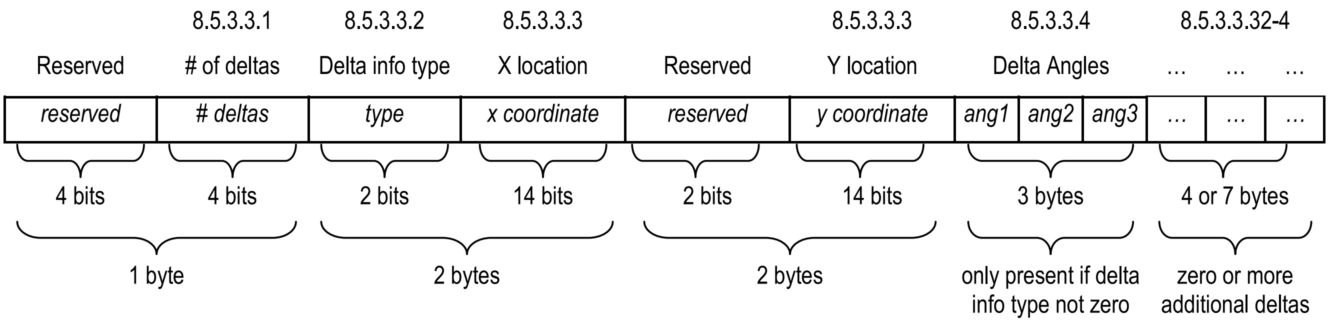
8.5.3.3.4 Delta angles

Each of the three angle attributes of the delta shall each be recorded in one byte in units of 1.40625 (360/256) degrees. The delta angle is measured increasing counter-clockwise starting from the horizontal axis to the right. The value shall be a non-negative value between 0 and 255, inclusive. For example, an angle value of 16 represents 22.5 degrees. If the delta information type is zero (Clause 8.5.3.3.2) then this field shall not be present. If not all three angles can be extracted from the image because of noise or image cropping, the angle fields affected shall be filled by repeating any of the other angle(s) for the same delta.

8.5.3.4 Core and delta format summary

The core and delta format shall be as follows:





8.5.4 Zonal quality data

8.5.4.1 General

If the extended data area type code is 0003_{Hex}, the extended data area contains zonal quality data. This format is provided to contain optional information about the quality of the fingerprint image within each cell in a grid defined on the original fingerprint image. Within each cell, the quality may depend on the presence and clarity of ridges, spatial distortions and other characteristics. Cell quality values are determined by the vendor.

8.5.4.2 Zonal quality vendor ID

To enable the recipient of the zonal 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).

8.5.4.3 Zonal 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 0000_{Hex} to $FFFF_{Hex}$.

8.5.4.4 Cell width and height

The number of pixels in cells in the x-direction (horizontal) shall be stored in one byte. Permissible values are 1 to 255. The number of pixels in cells in the y-direction (vertical) shall be stored in one byte. Permissible values are 1 to 255.

8.5.4.5 Cell quality information depth

The bit depth of the cell quality information shall be contained in one byte. This value will indicate the number of bits per cell used to indicate the quality. The permissible depth values shall be in the range of 1 to 8 bits.

8.5.4.6 Cell quality data

The quality of the fingerprint image in each cell shall be represented by one or more bits, as indicated in 8.5.4.5. Quality data for cells shall be stored in usual “raster” order – left to right, then top to bottom. If the finger image within this cell is of good clarity and significant ridge data is present, the cell quality shall be represented by higher values (by the bit value ‘1’ if the information depth is 1). If the cell does not contain significant ridge data, or the ridge pattern within the cell is blurred, broken or otherwise of poor quality, the cell quality shall be represented by lower values (the bit value ‘0’ if the information depth is 1).

The cell quality shall be packed into bytes. The last byte used to encode the zonal quality data shall be left justified with unused bits set to 0.

In cases where the size in the x-direction is not divisible by the cell width the number of cells shall be extended to include the rightmost region. The number of cells is then the rounded quotient of image width divided by cell width.

In cases where the size in the y-direction is not divisible by the cell height the number of cells shall be extended to include the bottommost region. The number of cells is then the rounded quotient of image height divided by cell height.

8.5.4.7 Zonal quality data format summary

The zonal quality data format shall be as follows:

8.5.4.2	8.5.4.3	8.5.4.4	8.5.4.4	8.5.4.5	8.5.4.6	
Zonal Quality	Zonal Quality	Cell Width	Cell Height	Cell InfoDepth		
Vendor ID	*Algorithm ID*	*x cell size*	*y cell size*	*Info depth*	*Cell quality bits*	*00…0*
2 bytes	2 bytes	1 byte	1 byte	1 byte	data bits	padding bits
					“Cell Data Length” bytes	

9 Finger minutiae on-card comparison format

9.1 Purpose

This clause defines the on-card biometric comparison related encoding format for a series of minutiae descriptions. This is the only finger minutiae on-card biometric comparison format defined and is limited to use on card-based systems only. It is not meant to be used as a storage format for data on any computer file system. Unlike the record type, this format has no provision for a general header record nor for individual finger representation headers. Therefore the encoded minutiae data should only be stored and compared on a card.

When this format is used, a series of minutiae descriptions as defined in clause 9.2 shall be embedded in a tag-length-value encoded biometric Data Object (DO) as defined in ISO/IEC 7816-11.

NOTE The term “card” is used for smartcards as well as for other kind of tokens.

9.2 On-card comparison format

9.2.1 Minutia placement

This on-card biometric comparison format requires that all ridge endings shall be encoded as either valley bifurcation points or ridge skeleton end points as defined in clause 6.4.3 and clause 6.4.5 respectively. If valley bifurcations are used, then the CBEFF BDB format type identifier 0005_{Hex} shall be used in the Biometric Information Template (BIT) defined in ISO/IEC 19785:3:2007. If ridge skeleton end points are used, then the CBEFF BDB format type identifier 0006_{Hex} shall be used.

9.2.2 Encoding

Using the on-card biometric comparison format three bytes are needed to encode each minutia. Table 14 illustrates the layout of the bits and bytes for minutiae position, type, and angle descriptors.

Table 14 - On-card biometric comparison format

x-coordinate	y-coordinate	type t	angle θ
1 byte	1 byte	2 bits	6 bits

9.2.3 Minutia position

The 8-bit X coordinate of the minutia shall be recorded in the first byte. The 8-bit Y coordinate shall be placed in the following byte. The coordinates shall be expressed such that each unit is equal to 10^{-1} mm. Ridge endings shall be encoded as ridge skeleton end points or valley bifurcation points.

NOTE The maximum value for the x and y coordinate is 25.5mm with the on-card biometric comparison format.

9.2.4 Minutia type

The type of minutia (type t) will be recorded in the most significant two bits of the byte whose less significant bits contain the angle value for the minutiae. The bits “00” will represent a minutia of “other” type, “01” will represent a ridge ending and “10” will represent a ridge bifurcation. Type “11” is reserved by SC 37 for future use.

9.2.5 Minutia angle

The angle of the minutia shall be recorded in six bits in units of 5.625 (360/64) degrees. The value shall be a non-negative value between 0 and 63, inclusive. For example, an angle value of 16 represents 90.0 degrees. Angle information shall be present for each minutia, regardless of type.

NOTE Minutiae of type “other” can represent either a ridge ending or ridge bifurcation when the minutia type cannot reliably be determined.

9.3 Number of minutiae and truncation

9.3.1 General aspects

The minutiae data of a finger consist of n minutiae encoded as shown in Table 14. The number n depends on:

- the minimum number of minutiae required according to the security level (see Annex D)
- the maximum number of minutiae accepted by a specific card e.g. due to buffer restrictions and computing capabilities.

The maximum number of minutiae accepted is therefore an implementation dependent value and shall be indicated in the Biometric Information Template, if the default value is not used (see Annex D).

A card may also require a special ordering of the minutiae presented in the biometric verification data. The ordering scheme shall be indicated in the Biometric Information Template (see ISO/IEC 19785 and ISO/IEC 7816-11), if the default value is not used.

9.3.2 Removing minutiae for card processing

If the number of minutiae exceeds the maximum number the card indicates it can accept, then minutiae shall be removed according to one of the following two options:

• Minutiae with the largest Euclidean distance from the centre of mass shall be removed first. The centre of mass shall be computed before any minutiae are removed.

• If minutia quality data is available, minutiae of the lowest quality are removed first. When any two minutiae share the same quality value, the one with the largest Euclidean distance from the centre of mass of a minutia set shall be removed first. The centre of mass shall be computed before any minutiae are removed. For minutiae that have the same quality and Euclidean distances, remove ridge ending first, and for minutiae of the same type, remove minutia with largest angle first.

Removal shall be conducted before any needed sorting of the minutiae.

This procedure shall apply to both the enrolment of a reference template, and the preparation of a verification template.

9.3.3 Lack of minutiae

If the number of minutiae is fewer than the minimum number indicated by the card the following options should be considered:

- re-acquisition of a sample from the subject
- use of a different finger
- prompt user or operator.

The implementation shall not assign fictional minutiae.

9.3.4 Biometric comparison algorithm parameters

Biometric comparison algorithm parameters are used to indicate implementation specific values to be observed by the outside world when computing and structuring the biometric verification data. They can be encoded as DOs embedded in a comparison algorithm parameter template as defined in ISO/IEC 19785-3, clause 11. Table 15 lists the DO biometric comparison algorithm parameters.

Table 15 - DO Biometric comparison algorithm parameters

Tag	Length	Value		
B1 Hex	var.	Biometric comparison algorithm parameters template		
		Tag	**Length**	**Value**
		81 Hex	2	Number of minutiae, see 9.3.5 8.3.3, Table 16
		82 Hex	1	Minutiae order, see 9.4 Table 17 & Table 18
		83 Hex	1	Feature handling indicator, see Table 20

9.3.5 Number of minutiae

For the indication of the minimum and maximum value of minutiae expected by the card the DO Number of minutiae as shown in Table 16 shall be used.

Table 16 -Data object for number of minutiae

Tag	L	Value
81_{Hex}	2	min (1 byte, binary coding) || max (1 byte, binary coding)

If this DO is not present in the BIT, the default values apply (see Annex D).

9.4 Minutiae order

9.4.1 Data object for minutiae ordering

For the indication of the ordering scheme for minutiae, the DO Minutiae order as shown in Table 17 shall be used.

Table 17 - Data object for minutiae order

Tag	L	Value
82_{Hex}	1	see Table 18

Table 18 - Values for minutiae order indication

b8	b7	b6	b5	b4	b3	b2	b1	Meaning
0	0	0	0	0	0	0	0	no ordering required (default value)
						0	1	ordered ascending
						1	0	ordered descending
			0	0	1			Cartesian x-y, see note 1
			0	1	0			Cartesian y-x
			0	1	1			Angle, see note 2
			1	0	0			Polar, root = center of mass
		1	0	0	0	0	0	X or Y coordinate extension for on-card biometric comparison format
x	x	x						000, other values are RFU

NOTE 1 Ordered by ascending/descending x-coordinate, if equal by ascending/descending y-coordinate (first x, then y)

NOTE 2 The angle represents the orientation of the minutia.

The minutiae shall be ordered according to the procedures of clauses 9.4.2 to 9.4.8.

9.4.2 Ordered ascending

Ordered ascending means, that the ordered sequence begins with the minutia from the original minutiae set, that has the smallest value of the indicated item. The value of this item increases with every successive minutia to the maximum value in the last minutia of the ordered sequence.

9.4.3 Ordered descending

Ordered descending means, that the ordered sequence begins with the minutia from the original minutiae set, that has the largest value of the indicated item. The value of this item decreases with every successive minutia to the minimum value in the last minutia of the ordered sequence.

9.4.4 Cartesian X-Y

Cartesian x-y stands for an ordering scheme, where first the x-coordinate is compared and used for ordering. When ordering by ascending Cartesian x-y coordinates, the minutia with minimum x-coordinate becomes the first minutia in the ordered sequence. The minutia with the second smallest x-coordinate becomes the second minutia in the ordered sequence. This process continues until the minutia with maximum x-value becomes the last minutia in the ordered sequence. If the x-coordinates in two or more minutiae are equal, the y-coordinate is compared for ordering.

9.4.5 Cartesian Y-X

Cartesian y-x stand for an ordering scheme, where first the y-coordinate is compared and used for ordering. If the y-coordinates in two or more minutiae are equal, the x-coordinate is compared for ordering.

9.4.6 Angle

Sorting a minutiae list by angle is done as follows. As defined in a previous section the angle of a minutia begins with value 0 to the right horizontal axis and increases counter-clockwise. When ordering by increasing angle, the minutia with the minimum angle value in the ordered sequence becomes the first minutia in the ordered sequence. The minutia with the second smallest angle value becomes the second minutia in the ordered sequence. This process continues until the last minutia in the ordered sequence is defined as the minutia with maximum angle value. No rules for subordering are defined, if the angle values in two or more minutiae are equal. Any possible ordering sequence of the minutiae with the same angle value is allowed in this case.

9.4.7 Polar

Polar is an ordering sequence by ascending or descending polar coordinates. First of all, a virtual coordinate root is defined as the center of mass of all minutiae. The polar coordinates of every minutia are computed as the relative distance and angle to this root coordinate. Without loss of generality, the process of ascending ordering with polar coordinates is described. The minutia with minimum Euclidean distance to the root becomes the first minutia in the ordered sequence. The minutia with the second smallest distance to the root becomes the second minutia in the ordered sequence. This process continues until the minutia with maximum distance to the root becomes the last minutia in the ordered sequence. If the root-distance of two minutiae or more is equal, the angle of these minutiae is compared. The minutia with the smallest angle as defined in 6.5.1 becomes the next minutia in the ordered sequence.

The position of the centre of mass of the minutiae shall be computed as the point specified by the means of the coordinates in X and Y.

$$x_{cm} = (x_1 + x_2 + ... + x_n) / n$$
$$y_{cm} = (y_1 + y_2 + ... + y_n) / n$$

where cm is the centre of mass and n is the number of minutiae.

9.4.8 X or Y Coordinate extension

The extracted X coordinates are sorted in ascending order and encoded in 2 bytes, but only the least significant byte is sent in the minutiae format to the card (equal to a mod(256) computation). The card can reconstruct the original sequence of values by adding 256 on all following entries when a violation of the ascending order occurs.

Example:

Original sequence:	60	276 277 333 581 797 860 986 1000
Transmitted sequence:	60	20 21 77 69 29 92 218 232

For each violation of the ascending order add 256 on all following entries:

	0	256 256 256 512 768 768 768 768
Reconstructed sequence:	60	276 277 333 581 797 860 986 1000

The same construction principle may alternately be applied also for the Y coordinate. Using this construction on X and Y together is not possible.

NOTE 1 Images with height larger than 256 pixels can occur when a four-finger slap impression is segmented below the first interphalangeal crease.

NOTE 2 It is assumed, that the distance between 2 neighbour minutiae is less than 256.

9.5 Usage of extended data for the on-card comparison format

9.5.1 Data objects for extended data

In the card format also, extended data beyond the finger minutiae may be present. In this case the usage of the biometric data template (tag $7F2E_{Hex}$) as described in ISO/IEC 7816-11 and defined in ISO/IEC 7816-6 is mandatory. Table 19 shows the biometric data template with its embedded data objects. If vendor-defined data are appended, then the biometric data in standardized format (DOs with tags 81_{Hex} and 91_{Hex} to 95_{Hex}) shall be encapsulated in the DO with tag $A1_{Hex}$, see Table 19.

9.5.2 Zonal quality data modified for on-card comparison minutiae formats

9.5.2.1 Zonal quality data format summary

In the absence of a record header, for the finger minutiae card formats the image size in X and Y direction is not provided; hence, the placement of the cells described in this clause is unknown. This information has to be provided in a modified header for the zonal quality data. The figure below shows the structure of zonal quality data in the finger minutiae on-card biometric comparison format.

9.5.2.2	9.5.2.3	9.5.2.3	9.5.2.4	9.5.2.5	
Density	Quality map width	Quality map height	Information depth		
# of cells per decimetre	*# of cells in X dir.*	*# of cells in Y dir.*	*depth*	*Cell quality bits*	*00…0*
1 byte	1 byte	1 byte	1 byte	Data bits	Padding bits

The first byte of the zonal quality data shall contain the spatial sampling rate of the quality map in cells per decimetre. The next two bytes shall contain the number of cells in the quality map in X and Y direction. The fourth byte gives the bit depth used for each cell. These header bytes shall be followed by the quality indication for each cell.

Table 19 - Biometric data template

Tag	Length	Value					Presence
$7F2E_{Hex}$	var.	Biometric data template					
		Tag	**Length**	**Value**			
		91_{Hex}	var.	Ridge count data according to 8.5.2.3			Optional
		92_{Hex}	var.	Core point data according to 8.5.3.4			Optional
		93_{Hex}	var.	Delta point data according to 8.5.3.4			Optional
		94_{Hex}	var.	Zonal quality data according to 9.5.2			Optional
		95_{Hex}	1	Impression type according to 8.4.13			Optional
		82_{Hex}/$A2_{Hex}$	var.	Biometric data with vendor specific format			Optional
		81_{Hex}	var.	Finger minutiae data			
				Field	Size (bits)	Valid Values	Multiple Instances
				X coordinate	8	[0,255]	
				Y coordinate	8	[0,255]	
				Minutiae Type	2		
				Minutiae angle	6	[0,63]	
		$A1_{Hex}$	var.	Constructed finger minutiae data in standard format			If DOs with tags 82_{Hex}/ $A2_{Hex}$ and at least one of the DOs with tags 91_{Hex} to 95_{Hex} are present
				Tag	**Length**	**Value**	
				81_{Hex}	var.	Primitive finger minutiae data in standard format	Mandatory if DO with tag $A1_{Hex}$ is present
				91_{Hex}	var.	Ridge count data	At least one of the DOs with tags 91_{Hex}–95_{Hex}
				92_{Hex}	var.	Core point data	
				93_{Hex}	var.	Delta point data	
				94_{Hex}	var.	Zonal quality data	
				95_{Hex}	1	Impression type	

NOTE The impression type supports enrolment of the same finger multiple times, once with each sensor. The ON-CARD BIOMETRIC COMPARISON engine might perform the comparison of the verification template with the enrolled template of the same type. If no impression type is present, the ON-CARD BIOMETRIC COMPARISON algorithm will try to compare with whatever template is stored for the finger to compare.

9.5.2.2 Density of cells in the quality map

This value shall indicate the number of cells in the quality map per decimetre. The density shall be uniform in X and Y direction. Permissible values are 20 to 255. The recommended value is 125 cells per decimetre.

9.5.2.3 Quality map width and height

The number of cells in X direction shall be stored in one byte. Permissible values are 1 to 255. The number of cells in Y direction shall be stored in one byte. Permissible values are 1 to 255.

9.5.2.4 Cell quality information depth

The bit depth of the cell quality information shall be contained in one byte. This value will indicate the number of bits per cell used to indicate the quality. Permissible values are 0, 1, 2, 4 and 8. With an information depth of 0 a rectangular image area of sufficient quality is defined by the width and height and the spatial sampling rate of the quality map.

9.5.2.5 Cell quality data

Refer to section 8.5.4.6 for a description of the cell quality data.

9.5.3 Indication of card capabilities

If a card with on-card biometric comparison supports one or more of the extended data, then the capabilities shall be indicated in the DO 'Biometric comparison algorithm parameters' (tag $B1_{Hex}$ within the BIT, as defined in ISO/IEC 19785-3) using the DO 'Feature handling indicator' (tag 83_{Hex}, value field 1 byte). The encoding of the feature handling indicator is defined in Table 20.

Table 20 - Encoding of feature handling indicator

b8	b7	b6	b5	b4	b3	b2	b1	Meaning
							1	Ridge count supported
						1		Core points supported
					1			Delta points supported
				1				Cell quality supported
x	x	x	x					RFU (default: 0)

10 Registered format type identifiers

The registrations listed in Table 21 have been made with the CBEFF Registration Authority (see ISO/IEC 19785-2) to identify the finger minutiae record format and the finger minutiae compare-on-card format. The format owner is ISO/IEC JTC 1/SC 37 with the registered format owner identifier 257 (0101_{Hex}).

Table 21 - Format type identifiers

CBEFF BDB format type identifier	Short name	Full object identifier
5 (0005_{Hex})	finger-minutiae-card-compact-valley-bifurcations	{iso registration-authority cbeff(19785) organization(0) jtc1-sc37(257) bdbs(0) finger-minutiae-card-compact-valley-bifurcations(5)}
6 (0006_{Hex})	finger-minutiae-card-compact-ridge-endings	{iso registration-authority cbeff(19785) organization(0) jtc1-sc37(257) bdbs(0) finger-minutiae-card-compact-ridge-endings(6)}
29 ($001D_{Hex}$)	finger-minutiae-record format	{iso registration-authority cbeff(19785) organization(0) jtc1-sc37(257) bdbs(0) finger-minutiae-record-version3(29)}

In the record format this ridge type information is coded in the representation header as defined in clause 8.4.17

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 minutiae 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)

Record format diagrams

B.1 Overall record format

8.3 General Header	8.4.1 Finger Minutiae Rep Header	8.4.19 Finger Minutiae Data	8.5 Extended Data Block	8.4.1 to 8.5 Finger minutiae representation
see B.2 below	*see B.3 below*	*see B.4 or B.5 Below*	*see B.6 below*	*See B.3 , B.4 or B.5, B.6 below*
One header per record 15 bytes	*One header per finger rep*	*Pixel or qualified pixel record*	*One extended block per representation*	*Zero or more additional finger minutiae representations*
		Finger minutiae representation		

B.2 General header format

8.3.1 Format ID	8.3.2 Version	8.3.3 Record Length	8.3.4 # of finger reps.	8.3.5 Device Certification flag
464D5200$_{Hex}$ ‘F’ ‘M’ ‘R’ 0 $_{Hex}$	30333000$_{Hex}$ ‘0’ ‘3’ ‘0’ 0 $_{Hex}$	*length*	*# of reps.*	*Cert Blocks Present*
4 bytes	4 bytes	4 bytes	2 bytes	1 byte

B.3 Finger minutiae representation format

8.4.2	8.4.3	8.4.4	8.4.5	8.4.6	8.4.7.2	8.4.7.3
Representation length	Capture date and time	Capture device technology identifier	Capture device vendor identifier	Capture device type identifier	Number of quality blocks	Quality Score
		See Table 5	*IBIA Assigned ID*	*Vendor assigned*		*0 to 100; 255*
4 byte	9 bytes	1 byte	2 bytes	2 bytes	1 byte	1 byte

8.4.7.4	8.4.7.5	8.4.7.3 - 8.4.7.5	8.4.8.2	8.4.8.3	8.4.8.4	8.4.8.3 – 8.4.8.4
Quality algorithm vendor ID	Quality algorithm ID	Zero or more additional quality blocks	Number of certification blocks	Certification authority	Certification Identifier	Zero or more additional certifications
IBIA Assigned ID	*Vendor Assigned ID*	*Quality, vendor ID, algorithm ID*		*IBIA Assigned ID*	*See Table 6*	*Authority Identifier*
2 byte	2 byte	5 bytes / additional quality block	1 byte	2 bytes	1 byte	3 bytes / additional certification

8.4.9	8.4.10	8.4.11	8.4.1.12	8.4.13	8.4.14	8.4.15
Finger position	Representation number	Image spatial sampling rate (horizontal)	Image spatial sampling rate (vertical)	Impression type	Horizontal image size	Vertical image size
See Table 7	*rep #*	*X-sampling rate*	*Y-sampling rate*	*See Table 8*	*X image size*	*Y image size*
1 byte	1 byte	2 bytes	2 bytes	1 byte	2 bytes	2 bytes

8.4.16	8.4.17	8.4.18
Minutiae field length	Ridge ending type	Number of minutiae
5 or 6	*0 or 1*	*Minutiae count*
4 bits	4 bits	1 byte

B.4 Qualified finger minutiae pixel record

8.4.19.1.2	8.4.19.1.3		8.4.19.1.3	8.4.19.1.2	8.4.19.1.3
Minutia Type	X location	Reserved	Y location	Minutia Angle	Minutia Quality
Type	*x coordinate*	*RFU 0* Hex	*y coordinate*	*angle, 0-255*	*0-100,254,255*
2 bits	14 bits	2 bits	14 bits	1 byte	1 byte
2 bytes		2 bytes			

B.5 Finger minutiae pixel record

8.4.19.1.2	8.4.19.1.3		8.4.19.1.3	8.4.19.1.2
Minutia Type	X location	Reserved	Y location	Minutia Angle
Type	*x coordinate*	*RFU 0* Hex	*y coordinate*	*angle, 0-255*
2 bits	14 bits	2 bits	14 bits	1 byte
2 bytes		2 bytes		

B.6 Extended data

8.5.1.1	8.5.1.2	8.5.1.3	8.5.1.4	8.5.1.2-4
Extended Data Block Length	Extended Data Type Code	Extended Data Length	Extended Data	Additional
Block Length	*Type ID code*	*Data length*	*data*	Extended …
2 bytes	2 bytes	2 bytes	("*Length*"-4) bytes	Data

Annex C
(informative)

Example data record

This example minutiae record demonstrates the format for a given set of data.

C.1 Data

Scanner ID = 00B5 $_{\text{Hex}}$ (this value is determined by the vendor); no certifications

Sensor Spatial sampling rate: 500 dpi in both X and Y axes; 196.85 pixels per cm, Image was 512 by 512 pixels

Plain live-scan prints of the left and right index fingers

Left Index: Finger quality is 90% of the maximum possible; 27 minutiae, listed in table below; no private feature data

Right Index: Finger quality is 70% of the maximum possible; 22 minutiae, listed in table below. Private feature data area (Type 0221_{Hex}) consisting of six bytes: 01_{Hex}, 44_{Hex}, BC_{Hex}, 36_{Hex}, 21_{Hex}, 43_{Hex} .

Record length = 397 = 15(record header) + 2 * 37 (finger headers) + 27 * 6 (minutiae for 1st finger) + 22 * 6 (minutiae for 2nd finger) + 2 (null private area for 1st finger) + 12 (private area for 2nd finger)

Minutia	Left Index Finger					Right Index Finger				
#	Type	X	Y	Angle	Quality	Type	X	Y	Angle	quality
1	Ending	100	14	112	90	ending	40	93	0	90
2	Ending	164	17	85	80	bifurcation	116	100	0	80
3	Bifurcation	55	18	22	90	ending	82	95	12	70
4	Bifurcation	74	22	76	60	bifurcation	140	113	15	70
5	Ending	112	22	90	80	ending	122	135	18	80
6	Bifurcation	42	31	44	90	bifurcation	55	72	21	50
7	Bifurcation	147	35	51	90	ending	94	74	24	60
8	Ending	88	38	165	40	ending	155	62	42	80
9	Bifurcation	43	42	4	80	bifurcation	42	64	55	70
10	Ending	56	48	33	70	ending	155	85	59	80
11	Ending	132	49	72	90	bifurcation	96	192	62	80
12	Bifurcation	71	50	66	80	ending	114	86	85	80
13	Other	95	51	81	90	bifurcation	142	90	90	70
14	Ending	112	53	132	50	ending	57	137	100	90
15	Bifurcation	135	58	32	80	ending	131	75	110	80
16	Other	41	60	59	70	ending	45	113	120	80
17	Bifurcation	67	62	145	90	bifurcation	111	171	130	50
18	Ending	91	63	132	80	ending	95	62	150	60
19	Ending	112	65	33	60	bifurcation	61	114	200	80
20	Ending	53	71	45	90	bifurcation	143	72	250	80
21	Bifurcation	104	74	12	80	ending	63	104	300	70
22	Ending	75	79	21	90	bifurcation	125	73	350	40
23	Bifurcation	48	80	92	90					
24	Ending	130	89	45	80					
25	Bifurcation	63	95	126	80					
26	Ending	47	108	164	90					
27	Bifurcation	126	115	172	30					

C.2 Example data format diagrams

8.3.1 Format ID	8.3.2 Version	8.3.3 Record length	8.3.4 # of finger reps.	8.3.5 Device dert. flag
464D5200Hex	'0''3''0' 0 Hex	0000018D Hex	0002 Hex	00 Hex

8.4.2 Representation length	8.4.3 Capture date and time	8.4.4 Capture device technology	8.4.5 Capture device vendor ID	8.4.6 Capture device type ID	8.4.7.2 Number of quality blocks
000000C9 Hex	07 D5 0C 0F 11 23 14 0000 Hex	00 Hex	ABCD Hex	00B5 Hex	01 Hex

8.4.7.3 Quality value	8.4.7.4 Quality vendor ID	8.4.7.5 Quality algorithm ID	8.4.9 Finger position	8.4.10 Representation number	8.4.11 X-spatial sampling rate
5A Hex	ABCD Hex	0123 Hex	07 Hex	00 Hex	00C5 Hex

8.4.12 Y-spatial sampling rate	8.4.13 Impression type	8.4.14 Horizontal image size	8.4.15 Vertical image size	8.4.16 Minutiae field length	8.4.17 Ridge ending type
00C5 Hex	00 Hex	200 Hex	200 Hex	6 Hex	0 Hex

8.4.18 Number of minutiae	8.4.19.1.2 Minutia #1 minutia Type	8.4.19.1.3 X location	8.4.19.1.3 Reserved	8.4.19.1.3 Y location	8.4.19.1.4 Minutia angle
1B Hex	01 Hex	0064 Hex	00 Hex	000E Hex	50 Hex

8.4.19.1.5 Minutiae quality	8.4.19.1.2 – 8.4.19.5 Remaining 26 minutiae	8.5.1.1 Extended data block length
5A Hex	……………………..	0000 Hex

8.4.2 Representation length	8.4.3 Capture date and time	8.4.4 Capture device technology	8.4.5 Capture device vendor ID	8.4.6 Capture device type ID	8.4.7.2 Number of quality blocks
000000B5 Hex	*07D5 0C 0F 11 23 14 0000 Hex*	*00 Hex*	*ABCD*	*00B5 Hex*	*01 Hex*

8.4.7.3 Quality value	8.4.7.4 Quality vendor ID	8.4.7.5 Quality algorithm ID	8.4.9 Finger position	8.4.10 Representation number	8.4.11 X-spatial sampling rate
46 Hex	*ABCD Hex*	*0123 Hex*	*02 Hex*	*01 Hex*	*00C5 Hex*

8.4.12 Y-spatial sampling rate	8.4.13 Impression type	8.4.14 Horizontal image size	8.4.15 Vertical image size	8.4.16 Minutiae field length	8.4.17 Ridge ending type
00C5Hex	*00 Hex*	*200 Hex*	*200 Hex*	*6 Hex*	*0 Hex*

8.4.18 Number of minutiae	8.4.19.1.2 Minutia #1 minutia Type	8.4.19.1.3 X location	8.4.19.1.3 Reserved	8.4.19.1.3 Y location	8.4.19.1.4 Minutia angle
16 Hex	*01 Hex*	*0064 Hex*	*00 Hex*	*000E Hex*	*50 Hex*

8.4.19.1.5 Minutiae quality	8.4.19.1.2 – 8.4.19.5 Remaining 21 minutiae
5A *Hex*	……………………..

8.5.1.1 Extended Data Block Length	8.5.1.2 Extended Data Type Code	8.5.1.3 Extended Data Length	8.5.1.4 Extended Data
000A Hex	*0221 Hex*	*0006 Hex*	*0144BC362143 Hex*

C.3 Raw data for the resulting minutiae record

Record Header:

464D5200303330000000018D000200 *Hex*

1st Finger header:

000000C907D50C0F112314000000ABCD00B5015AABCD0123070000C500C50002000200601B *Hex*

1st Finger minutiae data:

4064000E505A *Hex*	40A400113C50 *Hex*	80370012105A *Hex*
804A0016363C *Hex*	407000164050 *Hex*	802A001F1F5A *Hex*
80930023245A *Hex*	405800267528 *Hex*	802B002A0350 *Hex*
403800301746 *Hex*	40840031335A *Hex*	804700322F50 *Hex*
005F00333A5A *Hex*	407000355E32 *Hex*	8087003A1750 *Hex*
0029003C2A46 *Hex*	8043003E675A *Hex*	405B003F5E50 *Hex*
40700041173C *Hex*	40350047205A *Hex*	8068004A0950 *Hex*
404B004F0F5A *Hex*	80300050415A *Hex*	408200592050 *Hex*
803F005F5A50 *Hex*	402F006C755A *Hex*	807E00737A1E *Hex*

1st Private data area:

0000 *Hex*

2nd Finger header:

000000B507D50C0F112314000000ABCD00B50146ABCD0123020100C500C500020002006016 *Hex*

2nd Finger minutiae data:

4028005D005A *Hex*	807400640050 *Hex*	4052005F0946 *Hex*
808C00710B46 *Hex*	407A00870D50 *Hex*	803700480F32 *Hex*
405E004A113C *Hex*	409B003E1E50 *Hex*	802A00402746 *Hex*
409B00552A50 *Hex*	806000C02C50 *Hex*	407200563C50 *Hex*
808E005A4046 *Hex*	40390089475A *Hex*	4083004B4E50 *Hex*
402D00715550 *Hex*	806F00AB5C32 *Hex*	405F003E6B3C *Hex*
803D00728E50 *Hex*	808F0048B250 *Hex*	403F0068D546 *Hex*
807D0049F928 *Hex*		

2nd Private data area:

000A022100060144BC362143 ***Hex***

Annex D
(informative)

Handling of finger minutiae card formats

D.1 Enrolment

D.1.1 Number of minutiae

The number of minutiae is a security sensitive parameter and depending on the security policy of the application. Persons who do not meet the minimum required number for enrolment cannot be enrolled. The maximum number of minutiae for the reference data is implementation dependent.

The recommended minimum number of minutiae required for enrolment is 16 and for verification is 12. These values have an impact on the resistance of a minutiae-based biometric recognition system against zero-effort imposter attacks. The dependence of false match and false non-match rates on the number of minutia has been reported [MINEXII].

The maximum number of minutiae to be sent to a card is implementation dependent and related to:

- transmission time
- memory resources
- execution time and
- security aspects.

The recommended maximum value for enrollment and verification is 60. It is up to the extraction device to limit the number of minutiae sent to the card to 60 or the indicated value (see ISO/IEC 19785-3, clause 11)

D.1.2 Number of required finger presentations

The number of required finger presentations during an enrollment process is enrollment system dependent.

D.2 Comparison

The verification data is subject to translation (in x- and y-direction), rotation (deviation of the orientation) and distortion. Comparison also has to take into account components or factors like FAR/FRR.

D.2.1 Comparison conditions

The result of the comparing process is a score, which may denote the number of comparing minutiae or any other appropriate value. In interoperability tests, it may be verified whether different implementations of the comparison algorithm meet a required FAR/FRR e.g. in relation to the strength of function for the respective application.

D.2.2 Retry Counter

For on-card comparison, a retry counter (which is decremented by subsequent negative verifications and set to its initial value by positive verification) has to be implemented in order to limit the number of trials. The following aspects have impact on the initial value:

- experience of the user
- environmental conditions (e.g. construction of sensor embedding and finger placement)
- quality of verification data
- strength of function.

If the retry counter has reached the value 0, then the respective biometric verification method is blocked.

Resetting the retry counter to its initial value is possible, if supported, e.g. by using the RESET RETRY COUNTER command (see ISO/IEC 7816-4) with a resetting code (8 digits).

The recommended initial value of the retry counter lies in the range of 5 and 15. The security policy of the application provider and the required strength of function have impact on the possible range and the value applied.

D.3 Security aspects of finger minutiae presentation to the card

Fingerprints are left everywhere and therefore this kind of biometric data are considered to be public. An attacker may succeed in getting a good fingerprint of a person, derive from them the biometric verification data and present it to the stolen card of the respective person. To avoid this kind of attack and also replay attacks of data used in a previous verification process, a trusted path between card and service system is required. Such a trusted path is achieved by cryptographic means, e.g. using secure messaging according to ISO/IEC 7816-4. The specification of those secure messaging functions is usually application dependent and outside the scope of this part of ISO/IEC 19794.

Annex E
(normative)

Capture device certifications

E.1 Image quality specification for AFIS systems

E.1.1 General

These specifications apply to: (1) systems that scan and capture fingerprints[2] 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: (I) 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 E.1.2 and E.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 [18].

E.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 1,000 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 E.1 gives the preferred

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

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.

Table E.1 Preferred capture sizes

	Preferred Width (in)	(mm)	Preferred Height (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.

E.1.2.1 Linearity

E.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).

E.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.

E.1.2.2 Geometric accuracy

E.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:

$D \le 0.0007$, for $0.00 < X \le 0.07$

$D \le 0.01X$, for $0.07 \le X \le 1.50$

for 1,000-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.

E.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.

E.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 E.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 1,000-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 E1.2.3.

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.

E.1.2.3 Spatial frequency response

E.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 E.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 E.1 and E.2 for nominal test frequencies are given in Table E.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 E.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 E.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 E.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 E.3.

500-ppi scanner, for f = 1.0 to 10.0 cy/mm:

$$CTF = 3.04105E\text{-}04 * f^2 - 7.99095E\text{-}02*f + 1.02774 \qquad \text{(eq.E.1)}$$

1,000-ppi scanner, for f = 1.0 to 20.0 cy/mm:

$$CTF = -1.85487E\text{-}05*f^3 + 1.41666E\text{-}03*f^2 - 5.73701E\text{-}02*f + 1.01341 \qquad \text{(eq.E.2)}$$

E.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.

E.1.2.4 Signal-to-noise ratio

E.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.

E.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.

E.1.2.5 Gray-level uniformity

E.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.

E.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.

E.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.

E.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.

E.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.

E.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.

E.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.

E.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.

E.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

E.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 E.1.1, paragraph 2.

E.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.

E.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 E.1.2 of this annex as well as the following requirements.

E.1.3.1 Requirement – Capture protocol

The system shall provide a simple capture protocol.

E.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.

E.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.

E.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.

E.2 Image quality specification for personal verification

E.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.

E.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 [18].

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) nd (2) may need to be disengaged.

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

Table E.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

E.2.2.1 Geometric accuracy

E.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

E.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.

E.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 1.

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.

E.2.2.2 Spatial frequency response (SFR)

E.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[3].

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 E.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)

Table E.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

E.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.

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[3] 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.

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 2; 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.

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.

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.

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.

E.2.2.3 Gray-level uniformity

E.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.

E.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.

E.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.

E.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.

E.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.

E.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).

E.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.

E.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.

E.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.

E.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

E.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.

E.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.

E.3 Requirements and test procedures for optical fingerprint scanners

E.3.1 Introduction

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

E.3.2 Testing prerequisites

E.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 E.3.2.3)
- spreadsheet software
- suitable test targets (Clause E.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.

E.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.

E.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].

E.3.2.4 Demands on the test targets

E.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.

E.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.

E.3.3 Requirements and test procedures

E.3.3.1 Investigation of the grayscale linearity

E.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).

E.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.

E.3.3.1.3 Used targets

E.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.

E.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.

E.3.3.1.4 Test procedure

E.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.

E.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.

E.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.

E.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.

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

E.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: $D \le 0.0007$, for $0.00 < X \le 0.07$ and $D \le 0.01X$, for $0.07 \le X \le 1.50$
- for 1000 ppi scanners: $D \le 0.0005$, for $0.00 < X \le 0.07$ and $D \le 0.0071X$, for $0.07 \le X \le 1.50$

where $D = |Y-X|$, 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.

E.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.

E.3.3.2.3 Used targets

E.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.

E.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 influence 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.

E.3.3.2.4 Test procedure

E.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.

E.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.

E.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.

E.3.3.2.5 Requirement compliance

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

E.3.3.3 Investigation of the contrast transfer function

E.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 E.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 E.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-04 * f^2 - 7.99095E-02 * f + 1.02774 [EQ 1]

- 1000 ppi scanner, for f = 1.0 to 20.0 cy/mm: CTF = - 1.85487E-05*f^3 +1.41666E-03*f^2 - 5.73701E-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).

E.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 E.7:

Table E.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%

E.3.3.3.3 Used targets

E.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 tast 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.

E.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.

E.3.3.3.4 Test procedure

E.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.

E.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.

E.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.

E.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.

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

E.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.

E.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”.

E.3.3.4.3 Used targets

E.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.

E.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.

E.3.3.4.4 Test procedure

E.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.

E.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.

E.3.3.4.5 Requirement compliance

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

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

E.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.

E.3.3.5.2 Background

This test shows the scanner performance in normal operation mode.

E.3.3.5.3 Used targets

No targets are used in this test case.

E.3.3.5.4 Test procedure

E.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.

E.3.3.5.4.2 Test step 2

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

E.3.3.5.5 Requirement compliance

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

Annex F
(normative)

Detailed description of finger minutiae location, direction, and type

F.1 General

Even if all conform to this part of ISO/IEC 19794, different minutiae data blocks extracted from the same finger image may differ not only in the exact locations, the directions, and the types of those minutiae that they have in common, but also in the number of minutiae they contain, especially in blurred fingerprint regions where even the "manual" detection of minutiae is hard. The description of the minutia location in clause 6.4 of this part of ISO/IEC 19794 refers to a single-pixel-wide skeleton of the friction ridges. The minutia direction is defined in clause 6.4 of this part of ISO/IEC 19794 based on tangents to the skeleton. The skeletonisation algorithm itself is not described and also the method to determine the tangents is left open.

The scope of this informative annex is to provide a more precise definition of location, direction, and type of minutiae in gray-scale finger images and a detailed description of the quality field. It enhances the readability of this part of ISO/IEC 19794 and decreases the possibility of misinterpretation. The standardisation of algorithms is out of scope of this informative annex. This informative annex should not supersede the existing standard.

F.2 Terms and definitions

For the purposes of this informative annex, the following terms and definitions apply.

4-neighbour of a pixel *p*
pixel that is the top, bottom, left, or right neighbour of *p*

EXAMPLE The pixels *e*, *f*, *g*, and *h* in 0 are 4-neighbours of pixel *p*.

a	e	b
h	p	f
d	g	c

Figure F.1 4- and 8-neighbours of a pixel p

4-path from pixel p_0 to pixel p_n
sequence of pixels (p_0, p_1, p_2, …, p_n) such that p_i is a 4-neighbour of p_{i-1}

4-connected set of pixels
set *S* of pixels such that for any two pixels $p, q \in S$ there exists a 4-path from *p* to *q*

8-neighbour of a pixel *p*
pixel that is a 4-neighbour or a diagonal (top-left, top-right, bottom-left, or bottom-right) neighbour of *p*

EXAMPLE The pixels *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h* in 0 are 8-neighbours of pixel *p*.

8-path from pixel p_0 to pixel p_n
sequence of pixels (p_0, p_1, p_2, …, p_n) such that p_i is an 8-neighbour of p_{i-1}

8-connected set of pixels
set *S* of pixels such that for any two pixels $p, q \in S$ there exists an 8-path from *p* to *q*

border ∂S of a set of pixels *S*
subset $\partial S = \{x \in S : x \text{ is 4-neighbour of } q, q \notin S\}$ of pixels of *S* that are 4-neighbours of pixels outside *S*

F.3 Minutiae detection strategy

F.3.1 "Liberal-conservative" spectrum

Minutia detection algorithms may use different discriminative practices in the minutia detection strategy. A liberal minutia detection strategy is supposed to detect a large number of minutiae which will increase the probability to include spurious minutiae while a conservative strategy will detect only a few minutiae and increase the probability to miss some. The following subclauses provide an explanation of some types of spurious (false) minutiae which may result from the use of a 'liberal' strategy but which may not be detected if a more 'conservative' strategy is employed.

The following images show examples of applying a conservative or liberal minutia detection strategy to the same sample images. These examples are not meant to suggest a liberal or conservative strategy. The best detection strategy for a particular application depends on the business processes and their associated security requirements that the biometric components of the system are designed to support or enable.

Figure F.2 Liberal minutia detection (left) versus conservative minutia detection (right)

Figure F.3 Liberal minutia detection (left) versus conservative minutia detection (right)

Figure F.4 Liberal minutia detection (left) versus conservative minutia detection (right)

Figure F.5 Liberal minutia detection (left) versus conservative minutia detection (right)

Figure F.6 Liberal minutia detection (left) versus conservative minutia detection (right)

F.3.2 Fingerprint boundary

No minutia should be set outside the fingerprint boundary.

Minutiae may be set below the first phalange, even it is not the usual case.

F.3.3 Sweat pore

No minutia should be set at a sweat pore. A pore could happen to lie at the position of the forking of a friction ridge (bifurcation, see 0 below), but a sweat pore without connectivity to three legs should not be misinterpreted as a minutia.

F.3.4 Touching ridges

No minutia should be set where thick ridges touch each other.

F.3.5 Incipient ridge

No minutia should be set at an incipient (very short and thin) ridge.

F.3.6 Crease

No minutia should be set at a crease (accidental interruption of ridges).

F.3.7 Core

No minutia should be set at a core.

A core represents a singularity in the direction field, hence a proper angle value cannot be assigned to this location.

NOTE Information about cores can be expressed in a standardised way in the extended data block (see clause 8.5.3 of this part of ISO/IEC 19794).

F.3.8 Delta

No minutia should be set at a delta.

A delta represents a singularity in the direction field, hence a proper angle value cannot be assigned to this location.

NOTE Information about deltas can be expressed in a standardised way in the extended data block (see clause 8.5.3 of this part of ISO/IEC 19794).

F.4 Minutia characteristics

F.4.1 Rationale

This document should not standardize certain algorithms as laid down in the scope. The guidelines to find the best minutia position and location require some methodology in description. Examples of two independent methods for determining the location and orientation of minutiae are presented in this document. The first is commonly known as the ridge gradient method while the second is referred to as the valley skeletal bifurcation method, which is popular in the AFIS industry. Without loss of generality, the ridge gradient method will focus on ridge ends and ridge bifurcations and the valley skeletal bifurcation method will describe valley bifurcations and ridge bifurcations in this document, i.e. the choice of the method finally depends on the specific format type to be used.

F.4.2 Minutia type

The minutia type cannot be determined reliably in some occasions.

EXAMPLE Due to varying contact pressure while acquiring the fingerprint and due to different image binarisation approaches, a ridge ending may join an adjacent ridge, giving the impression of a ridge bifurcation.

The minutiae type “other” should only be used if neither of the other two minutiae types, “ridge ending” and “ridge bifurcation”, can reliably be assigned to a minutia.

F.4.3 Minutia location tools

F.4.3.1 Consideration of the spatial sampling rate of the underlying finger image

For the minutiae location, a correct handling of the spatial sampling rate of the underlying finger image is important. The minutiae extraction algorithm should be able to determine the spatial sampling rate of the underlying finger image in a reliable way (e.g. from a fingerprint-sensor configuration file). For minutiae data in the finger minutiae record format, this spatial sampling rate should be stored in the X and Y spatial sampling rate fields within the record header. For minutiae data in the on-card-biometric-comparison format, the spatial sampling rate of the underlying finger image should be used when calculating the X and Y coordinates of the location in the prescribed metric dimension units out of their pixel values. For conversion between format types, the spatial sampling rate should be taken from, or stored in, the X and Y spatial sampling rate fields within the record header.

F.4.3.2 Image binarisation

Every gray scale fingerprint image can be transformed into a binary image. This is common practice in image processing. Every pixel is assigned black if its gray scale value is darker than a threshold (such as the average gray scale value) and white if its gray scale value is lighter than the threshold. Most professional finger image processing implementations use sophisticated methods such as location-dependent thresholds to come to a binary image. A binary image separates the image pixels into two categories: ridges and valleys. Without loss of generality, black pixels refer to ridges in the following text.

captured raw image   binary image (truncated)

Figure F.7 Raw image vs. binary image

F.4.3.3 Image skeletonization

Skeletonization is a standard procedure in graphing practice. It produces a single-pixel-wide skeleton from a binary image. Several skeletonization methods are reported in literature. The process yields either a 4-connected or 8-connected skeleton. The following figure shows a sample image and its skeleton.

Figure F.8 Binary image and ridge skeleton, from [17]

As valley skeletons will also be used in this part of ISO/IEC 19794, another figure depicts the valley skeleton of the same image.

Figure F.9 Binary image and valley skeleton, from [17]

F.4.3.4 Ridge flow direction

Every fingerprint image has a well defined directional image expressing the local dominant ridge flow direction. Methods to compute a directional image are reported in literature, e.g. [15]. 0 shows a fingerprint image and its directional image.

Figure F.10 Raw image and pixel-wise directional image, from [17]

Most current fingerprint minutiae detection algorithms are working with a block-wise directional image rather than a pixel-wise. The original directional image is therefore divided into blocks and the most common orientation within a block becomes the orientation for the whole block. The next picture shows the block directional image.

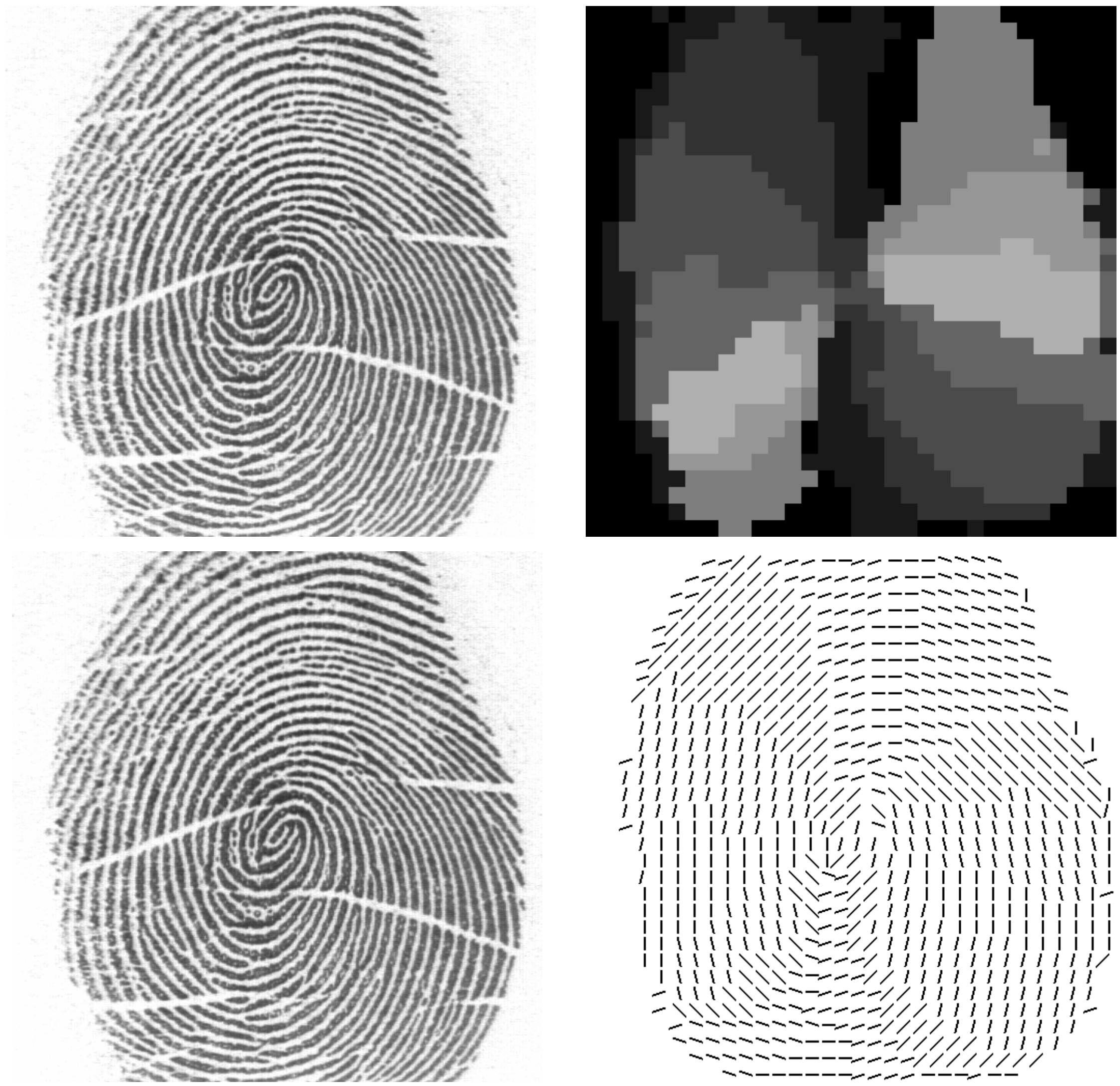

Figure F.11 Raw image and block-wise directional image, from [17]

F.4.4 Ridge gradient method

The ridge gradient method relies on moving along the ridge line until a minutia condition occurs, which is either forking or ending of the ridge. It was originally reported for gray-scale images [16], but is described here for binary images to simplify the procedure, which has only a descriptive nature in this document.

F.4.4.1 Minutia location at a ridge skeleton endpoint

Friction ridges in a binary image have a well defined border: Black pixels with at least one white pixel as 4-neighbour are border pixels of a friction ridge. This ensures that the border is at least 8-connected. The border of a ridge skeleton endpoint is depicted in Figure F.12.

Figure F.12 Border of a ridge skeleton endpoint

Skeletonisation algorithms should reduce the friction ridges of a binary fingerprint image to a single pixel wide skeleton. Instead of discussing how the skeletonisation algorithm should work, another approach to describing where to place the minutiae is preferred. Every ridge has a dominant ridge flow direction. The dominant ridge flow direction (see F.4.3.4) line meets the border of the ridge in a single pixel of the binary image. This pixel is considered the optimal minutia location.

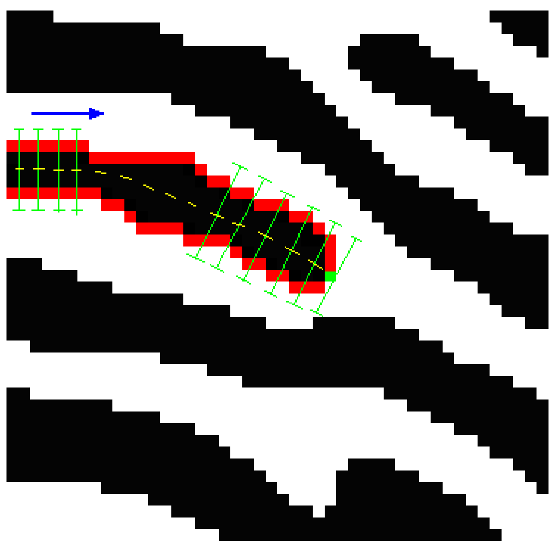

Figure F.13 Minutia location on a ridge skeleton endpoint

F.4.4.2 Minutia location at a ridge skeleton bifurcation point

The border at a ridge bifurcation is well defined. The three parts of the border are not necessarily connected. The border of a ridge skeleton bifurcation point is depicted in Figure F.14.

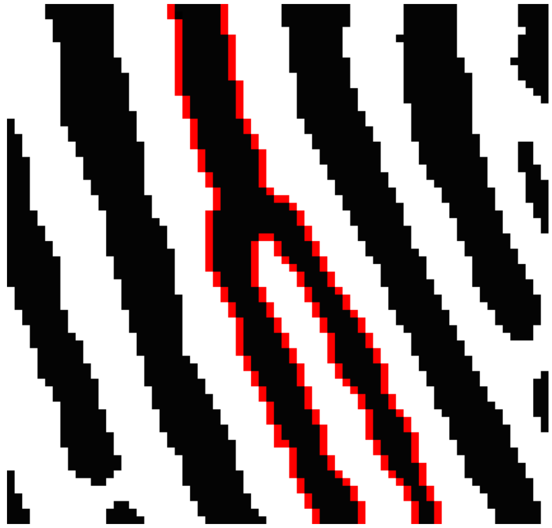

Figure F.14 Border of a ridge skeleton bifurcation point

The dominant ridge flow direction lines along all three legs meet in a single point or form a small triangle within the ridge. The single intersecting point is considered the optimal minutia location. It is most likely half a ridge width from the border pixel where an acute angle is enclosed by neighbouring legs. It could happen rarely and depending on the image spatial sampling rate that the three legs do not intersect in a single pixel but form a small triangle at intersection. In this case, the optimal minutia position is the center of mass of the triangle.

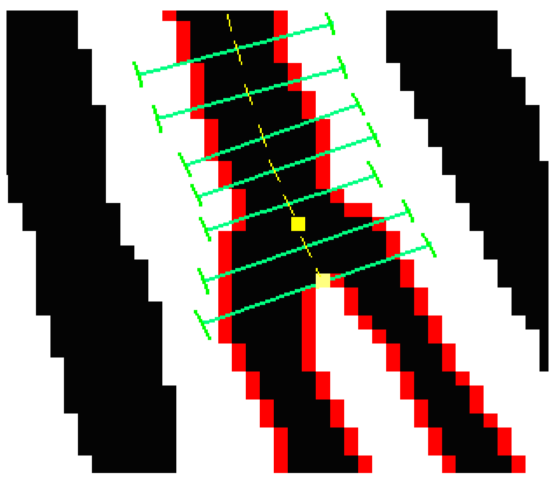

Figure F.15 Minutia location on a ridge skeleton bifurcation point

F.4.4.3 Minutia location at a valley skeleton bifurcation point

Analogical rules as for ridge skeleton bifurcation points apply also for valley skeleton bifurcation points. The valley skeleton bifurcation point is described in detail in the section using the valley skeletal bifurcation method to determine minutia position and orientation.

F.4.4.4 Minutia direction at a ridge skeleton endpoint

This part of 19794 defines the minutia direction at a ridge skeleton endpoint as the angle measured counter-clockwise from the positive X axis to the tangent to the skeleton, at the ridge skeleton endpoint. There are several methods to determine the tangent to a curve. The following procedure is a recommended method to find the tangent: A circle is drawn around the minutia point. The radius should be 1,63mm (This is equivalent to 32 pixels at 19.69ppmm/500 ppi and approximately the average width of 3 ridges of adult persons). The circle hits the skeleton of the ridge on which the minutia resides in a single pixel. If the ridge skeleton is not available, the intersection of the ridge with the circle has a well-defined centre to approximate. A line is drawn form the minutia point through the intersection respectively its centre point. It approximates the tangent to the ridge.

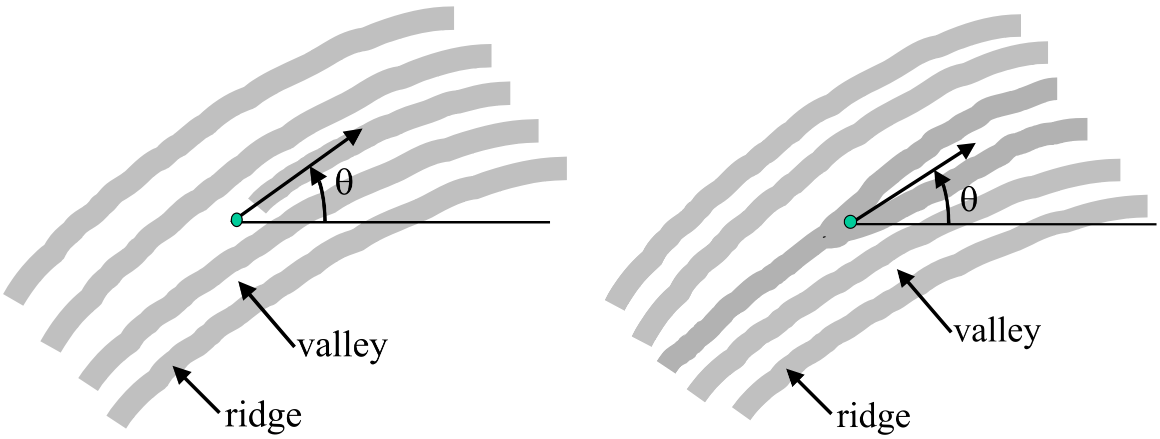

Figure F.16 Minutia direction on a ridge skeleton endpoint and bifurcation point, equivalent to figure 2 and figure 3 from Clauses 6.4

F.4.4.5 Minutia direction at a ridge skeleton bifurcation point

A circle should be drawn around the minutia. The radius should be 1.63mm (average width of 3 ridges of adult persons). The circle hits the skeleton of the ridge bifurcation on which the minutia resides in three pixels. Alternatively, the circle crosses every leg of the bifurcation once and with a well-defined centre. The intersecting points respectively centres of intersections are connected with the minutia. The connections define three angles, including only one acute angle. The angle measured counter-clockwise from the positive X axis to the bisecting line of this acute angle is the minutia direction.

F.4.4.6 Minutia direction at a valley skeleton bifurcation point

Analogical rules as for ridge skeleton bifurcation points apply also for valley skeleton bifurcation points. Valley skeleton bifurcation points will be discussed in the valley skeletal bifurcation extraction method.

F.4.5 Valley skeletal bifurcation method

The valley skeletal bifurcation method determines both the ridge and valley skeleton and works on this data to determine the position, type and orientation of ridge bifurcations and valley bifurcations (representing ridge ends).

The position or location of a minutia representing a medial valley ridge ending should be the point of forking of the medial skeleton of the valley area immediately in front of the ridge ending. If the three legs of the valley area were thinned down to a single-pixel-wide skeleton, the point of the intersection is the location of the minutia. Similarly, the location of the minutia for a bifurcation should be the point of forking of the medial skeleton of the ridge. If the three legs of the ridge were each thinned down to a single-pixel-wide skeleton, the point where the three legs intersect is the location of the minutia.

After all ridge endings have been converted to bifurcations, all of the minutiae of the fingerprint image are represented as bifurcations. The X and Y pixel coordinates of the intersection of the three legs of each minutia can be directly formatted. Determination of the minutia direction can be extracted from each skeleton bifurcation. The three legs of every skeleton bifurcation should be examined and the endpoint of each leg determined. The Diagrams below illustrate the three methods used for determining the end of a leg. The ending is established according to the event that occurs first:

- A distance of 1,63mm
- The end of skeleton leg that occurs between a distance of 0,50mm and 1,63mm; legs shorter than 0.5mm are not used. This applies to both naturally short legs and those legs that fall into the background region
- A second bifurcation is encountered within a distance of 1,63mm

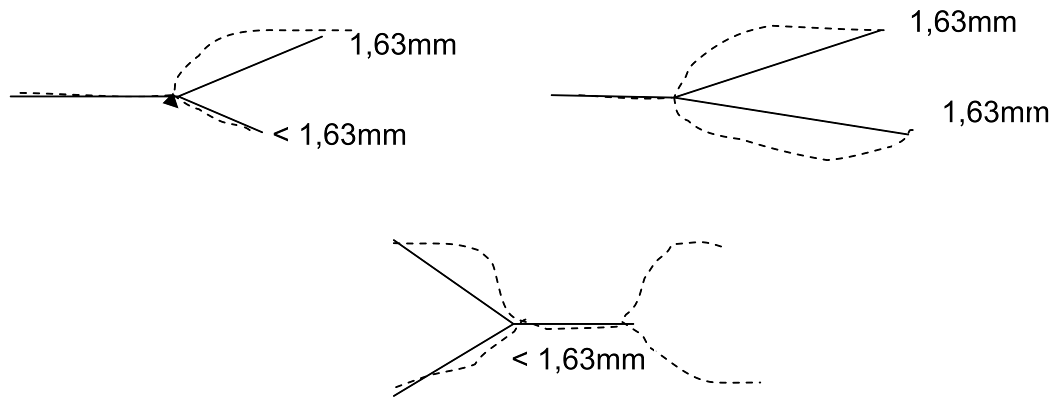

Figure F.17 Methods used to determine the end of a leg

The angle of the minutiae is determined by constructing three virtual rays originating at the bifurcation point and extending to the end of each leg. The smallest of the three angles formed by the rays is bisected to indicate the minutiae direction.

F.4.5.1 Minutia location at a valley skeleton bifurcation

The minutia for a ridge ending should be defined as the point of forking of the medial skeleton of the valley area immediately in front of the ridge ending (refer to Figure F.19 below). If the valley area were thinned down to a single-pixel-wide skeleton, the point where the three legs intersect is the location of the minutia. In simpler terms, this is the point where the valley “Y”’s, or (equivalently) where the three legs of the thinned valley area intersect. A Ridge Ending should be encoded only if all of the legs used to calculate the minutiae angle length (as defined in F.4.5.3 – Angle of a Ridge Ending) are >= 0,50mm in length.

F.4.5.2 Minutia location at a ridge skeleton bifurcation

The minutia for a ridge bifurcation should be defined as the point at which a ridge splits into two ridges. The ridge bifurcation is located at the center of the intersection of three ridges. If a thinned image is considered, it is the location of the pixel with three neighbours. A Ridge Bifurcation should be encoded only if the legs used to calculate the minutiae angle (as defined in F.4.5.4 Angle of a Ridge Bifurcation) are >= 0,50mm in length.

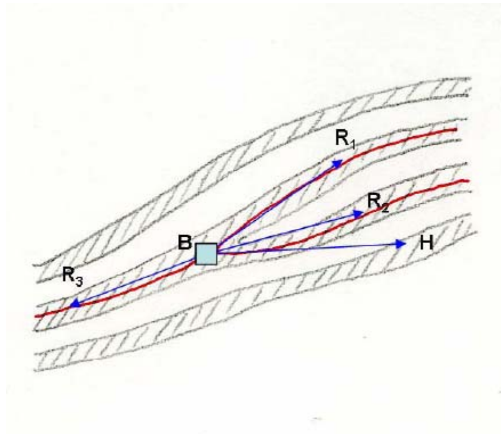

Figure F.18 Minutia location on a ridge bifurcation

F.4.5.3 Angle of a ridge ending

Determination of the minutia direction can be extracted from each skeleton bifurcation. The three legs of every skeleton bifurcation should be examined and followed for 1,63mm; special cases are outlined below. The angle of the minutiae is determined by constructing three virtual rays originating at the bifurcation point and extending to the end of each leg. The smallest of the three angles formed by the rays is bisected to indicate the minutiae direction.

Four cases are possible; see Figure F.19 through Figure F.22. In these figures, the shaded regions represent fingerprint ridges, the red lines represent the valley skeleton, and the blue lines represent the legs and horizontal axis.

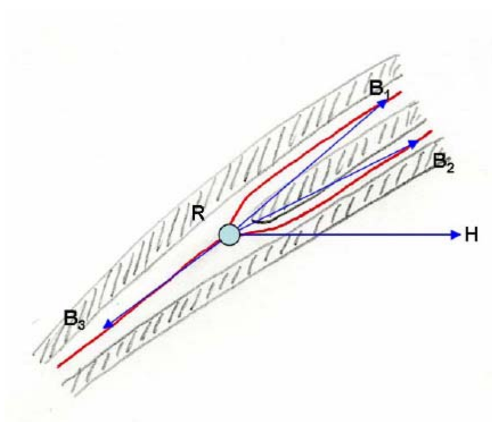

Figure F.19 Case 1: Three legs of valley bifurcation with length >= 1,63mm

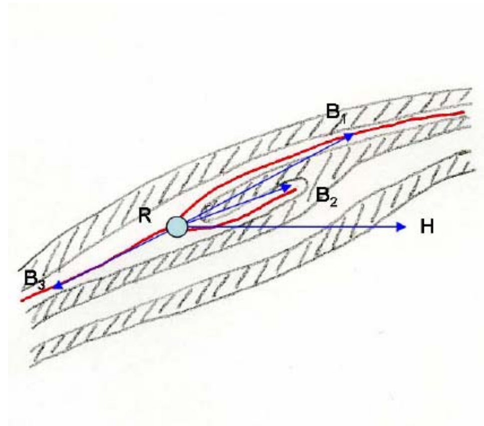

Figure F.20 Case 2: One leg of valley bifurcation with length < 1,63mm but >= 0,50mm

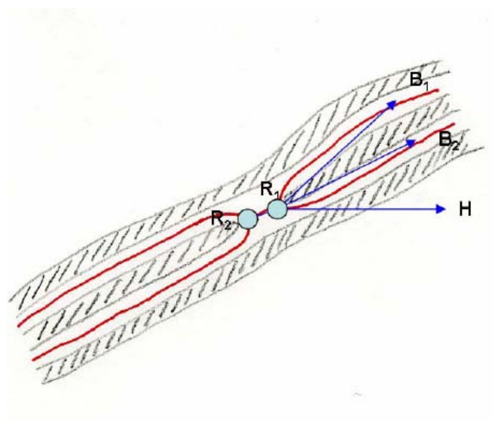

Figure F.21 Case 3: Third leg meets opposite valley bifurcation with length < 1,63mm but >= 0,50mm

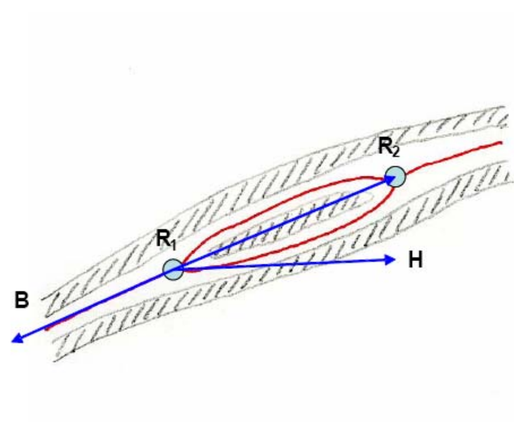

Figure F.22 Case 4: Ridge with length < 1,63mm but >= 0,50mm

Note (informative) – While the formulas for cases (1) and (2) are identical, the cases are shown separately to illustrate how to calculate the angle for a ridge ending when it is not possible to follow a leg for 1,63mm

(1) Figure F.19 illustrates the case where the lengths of three legs, RB_1, RB_2, and RB_3, >=1,63mm. The angle of the ridge ending, R, is defined as:
Angle of R = (Angle B_1RH + Angle B_2RH) / 2, where the line RH parallels the horizontal axis.

If the line RH bisects the legs RB_1 and RB_2, the angle of the ridge ending, R, is defined as:
Angle of R = ((Angle B_1RH + Angle B_2RH) / 2) - 180º, where angles outside the range of 0º–359º should be normalized to fall within this range.

(2) Figure F.20 illustrates a case similar to (1), but the length of one of the legs of the paralleled valley bifurcation, RB_2, is < 1,63mm, but >= 0,50mm. The angle of the ridge ending, R, is defined as:
Angle of R = (Angle B_1RH + Angle B_2RH) / 2, where the line RH parallels the horizontal axis.

If the line RH bisects the legs RB_1 and RB_2, the angle of the ridge ending, R, is defined as:
Angle of R = ((Angle B_1RH + Angle B_2RH) / 2) - 180º, where angles outside the range of 0º–359º should be normalized to fall within this range.

(3) Figure F.21 illustrates a case similar to (1), but with the lengths of two legs, $R_1B_1$and R_1B_2, of the paralleled valley bifurcation >= 1,63mm, but the third leg, R_1R_2, meets the other valley bifurcation and the length R_1R_2 < 1,63mm , but >= 0,50mm. The angle of the ridge ending, R1, is defined as:
Angle of R_1 = (Angle B_1R_1H + Angle $B_2 R_1H$) / 2, where the line RH parallels the horizontal axis.

If the line R_1H bisects the legs R_1B_1 and R_1B_2, the angle of the ridge ending, R_1, is defined as:
Angle of R_1 = ((Angle B_1R_1H + Angle $B_2 R_1H$)1) / 2) - 180º, where angles outside the range of 0º–359º should be normalized to fall within this range.

(4) Figure F.22 illustrates the case where two paralleled valleys meet together at a valley bifurcation and the length of both legs are < 1,63mm, but >= 0,50mm and the length of the third leg >= 1,63mm. The angle of the ridge ending, R1, is defined as:
Angle of R_1 = Angle R_2R_1H, where the line R_1H parallels the horizontal axis.

If the line R_1H intersects R_2, the angle of the ridge ending, R_1 is 0^0.

Figure F.23 illustrates (1) above, where point R is a valley bifurcation while points B_1, B_2, and B_3 represent the end points that lie on thinned valley skeleton lines, at a distance of 1,63mm from each end point in the direction into the enclosed ridge ending, R. The angle of the ridge ending R is the average of the angles B_1RH and B_2RH.

Figure F.24 illustrates (2) above, where point R is a ridge ending while points B_1, B_2, and B_3 represent the nearest valley end points. The distance between R and B_2 is < 1,63mm, but >= 0,50mm while the lengths of the other two legs, RB_1 and RB_3, >= 1,63mm. The angle of ridge ending R is the average of the angles B_1RH and B_2RH.

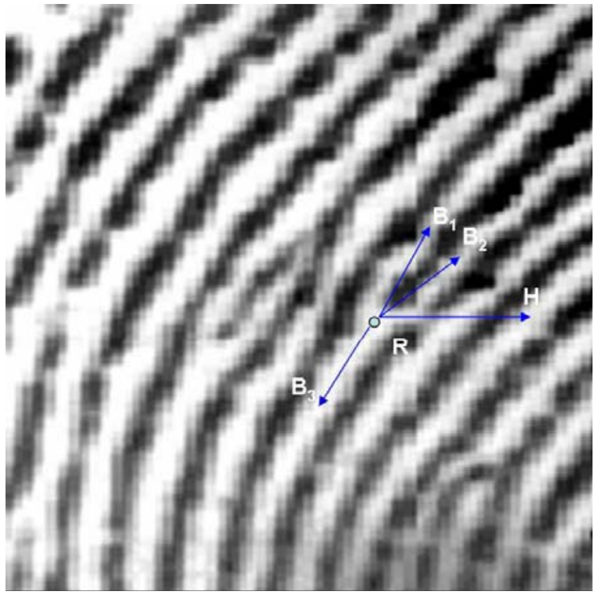

Figure F.23 Valley bifurcation location and angle with the length of segment >= 1,63mm

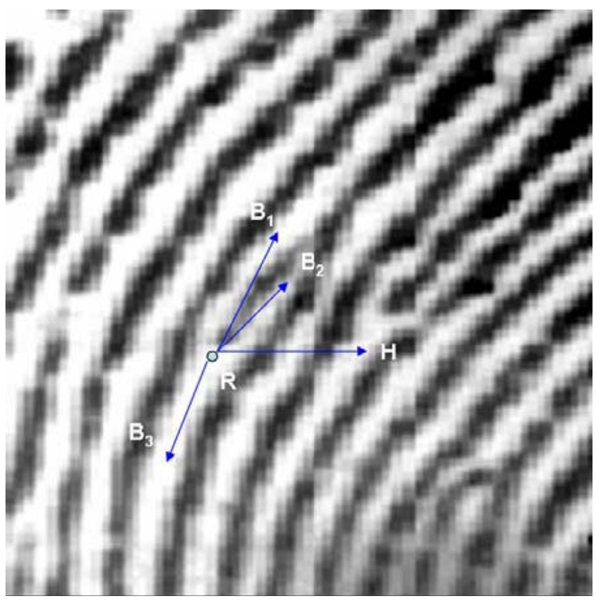

Figure F.24 Valley bifurcation location and angle with the length of segment < 1,63mm

F.4.5.4 Angle of a ridge bifurcation

Determination of the minutia direction can be extracted from each skeleton bifurcation. The three legs of every skeleton bifurcation should be examined and followed for 1,63mm; special cases are outlined below. The angle of the minutiae is determined by constructing three virtual rays originating at the bifurcation point and extending to the end of each leg. The smallest of the three angles formed by the rays is bisected to indicate the minutiae direction.

Four cases are possible; see Figure F.25 through Figure F.28. In these figures, the shaded regions represent fingerprint ridges, the red lines represent the ridge skeleton, and the blue lines represent the legs and horizontal axis.

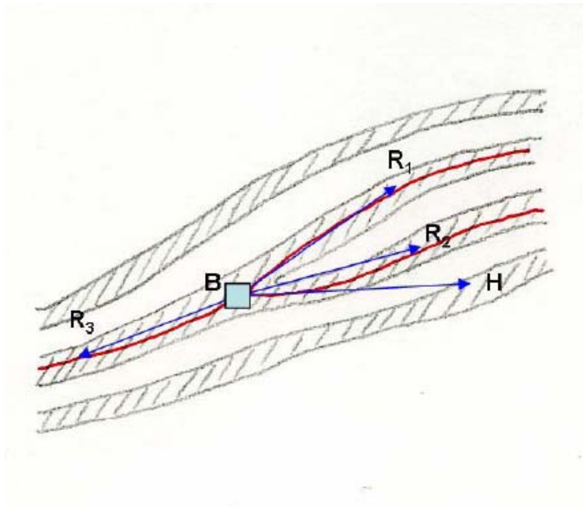

Figure F.25 Case1: Three legs of ridge bifurcation with length >= 1,63mm

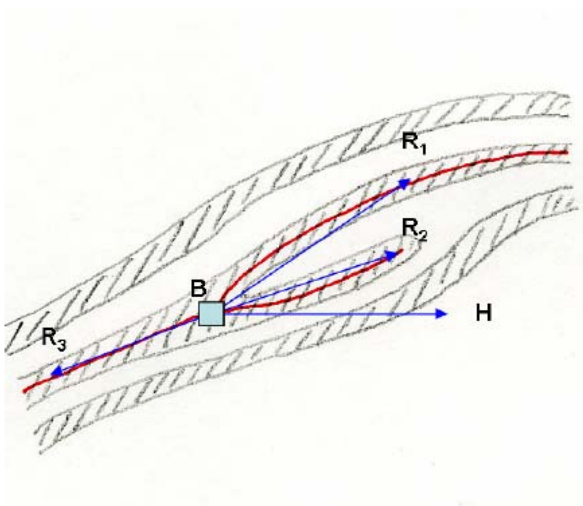

Figure F.26 Case 2: One leg of the ridge bifurcation with length < 1,63mm but >= 0,50mm

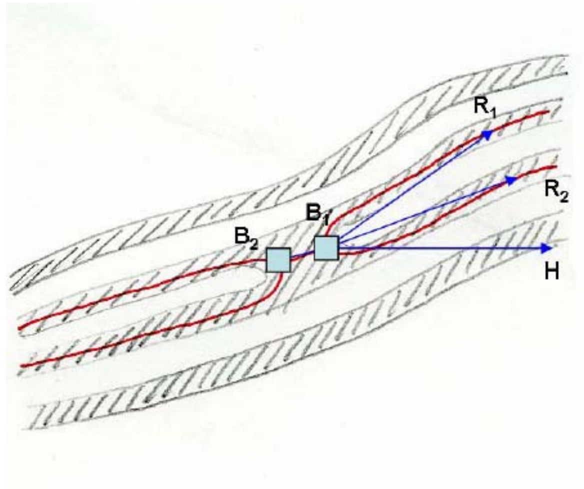

Figure F.27 Case 3: Third leg meets the opposite ridge bifurcation with length < 1,63mm but >= 0,50mm

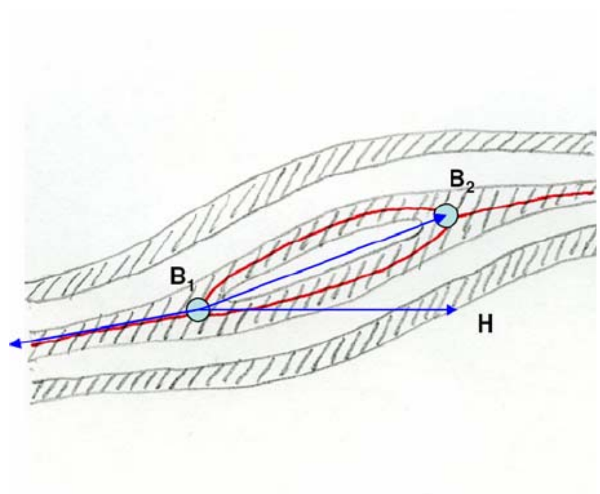

Figure F.28 Case 4: Ridges with length < 1,63mm but >= 0,50mm

Note (informative) – While the formulas for cases (1) and (2) are identical, the cases are shown separately to illustrate how to calculate the angle for a ridge bifurcation when it is not possible to follow a leg for 1,63mm.

(1) Figure F.25 illustrates the case where the lengths of three legs, BR_1, BR_2, and BR_3 >=1,63mm. The angle of the bifurcation, B, is defined as:

Angle of B = (Angle R_1BH + Angle R_2BH) / 2, where the line BH parallels the horizontal axis.

If the line BH bisects the legs BR_1 and BR_2, the angle of the bifurcation, B, is defined as:

Angle of B = ((Angle R_1BH + Angle R_2BH) / 2) - 180º, where angles outside the range of 0º–359º should be normalized to fall within this range.

(2) Figure F.26 illustrates a case similar to (1), but the length of one of the legs of the paralleled ridge bifurcation, BR_2, is < 1,63mm, but >= 0,50mm. The angle of the bifurcation, B, is defined as:

Angle of B = (Angle R_1BH + Angle R_2BH) / 2, where the line BH parallels the horizontal axis.

If the line BH bisects the legs BR_1 and BR_2, the angle of the bifurcation, B, is defined as:

Angle of B = ((Angle R_1BH + Angle R_2BH) / 2) - 180º, where angles outside the range of 0º–359º should be normalized to fall within this range.

(3) Figure F.27 illustrates a case similar to (1), but with the lengths of two legs, B_1R_1 and B_1R_2, of the paralleled valley bifurcation >= 1,63mm, but the third leg, B_1B_2, meets the other ridge bifurcation and the length B_1B_2 <1,63mm, but >= 0,50mm. The angle of the bifurcation, B_1, is defined as:

Angle of B_1 = (Angle R_1B_1H + Angle R_2B_1H) / 2, where the line B_1H parallels with the picture horizontal axis.

If the line B_1H bisects the legs BR_1 and BR_2, the angle of the bifurcation, B, is defined as:

Angle of B_1 = ((Angle R_1B_1H + Angle R_2B_1H) / 2) - 180º, where angles outside the range of 0º–359º should be normalized to fall within this range.

(4) Figure F.28 illustrates the case where two paralleled ridges meet together at a ridge bifurcation and the length of both legs are < 1,63mm but >= 0,50mm and the length of the third leg >= 1,63mm. The angle of the bifurcation, B_1, is defined as:

Angle of B_1 = Angle B_2B_1H, where the line B_1H parallels with the picture horizontal axis.

If the line B_1H intersects B_2, the angle of the bifurcation, B_1, is 0º.

Figure F.29 illustrates (1) above, where point B is a ridge bifurcation while points R_1, R_2, and R_3 represent the end points that lie on thinned ridge skeleton lines, at a distance of 1,63mm from each end point in the direction into the bifurcation, B. The angle of bifurcation B is the average of the angles R_2BH and R_1BH.

Figure F.30 illustrates (2) above, where point B is a ridge bifurcation while R_1, R_2, and R_3 represent the nearest ridge end points. The distance between B and R_2 is < 1,63mm, but >= 0,50mm while the length of the other two legs, BR_1, and BR_3, >=0.064”. The angle of bifurcation B is the average of the angles R_2BH and R_1BH.

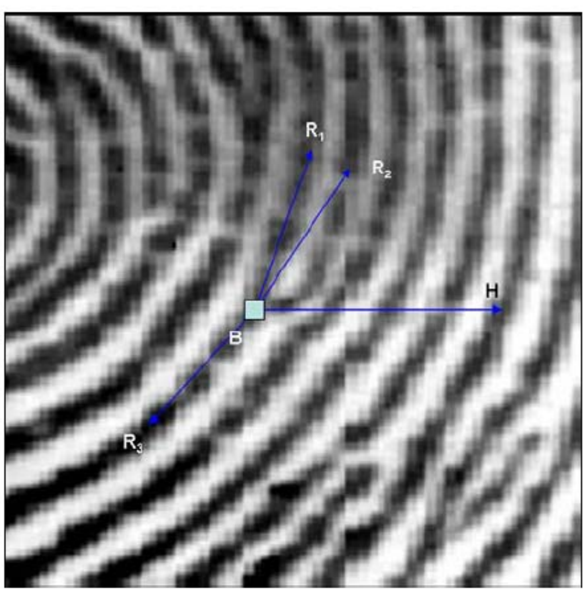

Figure F.29 Bifurcation location and angle with the length of segment >= 1,63mm

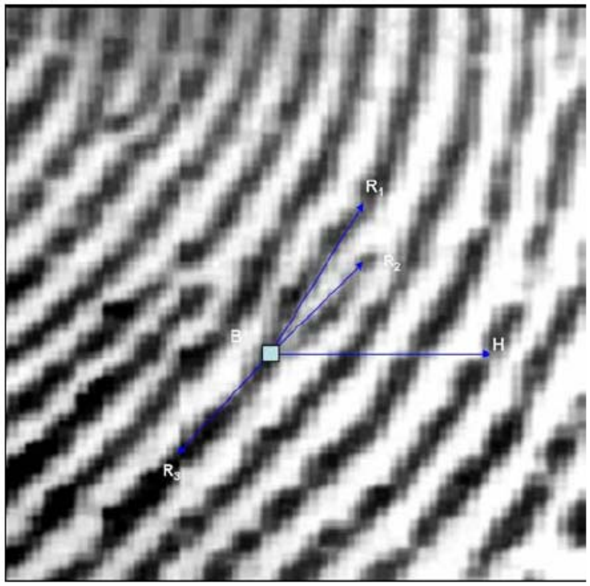

Figure F.30 Bifurcation location and angle with the length of segment < 1,63mm

F.4.6 Minutia quality

The value should correspond to the likelihood that the current minutia is not a false minutia.

A precise definition of the quality field is subject to national body contributions.

F.5 Sample image

The following shows a sample image with extracted minutia data.

Figure F.31 Sample image with extracted minutiae, from [12]

The compact metric format was used to encode the minutiae in the above fingerprint image. This means that one byte is used for the x-coordinate, the second byte for the y-coordinate and the third byte for the direction with the type in the most significant two bits.

This results in the following data (hexadecimal):

5D 69 2D A1 43 2F AA 82 2F 6F 48 2F 43 49 35 96 45 37 AF 81 48 B0 BF 48 96 48 48 5D 89 4A 9C 43 4D 7C 6A 4D 63 6A 4D 19 45 4F 73 8B 50 91 42 54 85 6B 57 6B AA 58 86 B2 58 7D 70 59 36 82 5B 8C 57 5E 94 9C 5F 73 71 61 61 66 64 4C 9C 69 97 9B 6F A5 9D 70 33 B9 72 50 96 74 92 58 7D 27 59 7E 9D 59 80 66 93 83 4A 56 86 8E 56 90 3D 74 9A 3A 76

The first minutia has the horizontal position $5D_{Hex}$ and the vertical position 69_{Hex}. It is a ridge end (third byte smaller than 80_{Hex}) with angle $2D_{Hex}$. Other minutine are encoded accordingly.

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