MTR 04B0000022

MITRE TECHNICAL REPORT

Profile for 1000ppi Fingerprint Compression

Version 1.1

April 2004

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Sponsor: DOJ / FBI
Dept. No.: G036
Contract No.: W15P7T-04-C-D001
Project No.: 0704E02X

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Abstract

This document specifies a format for use in compressing 1000ppi fingerprints. This format is a profile (usage subset) of the ISO/IEC 15444-1 JPEG 2000 image compression standard. Compliance testing procedures are described for this profile.

KEYWORDS: JPEG 2000, JP2, fingerprint compression, 1000 ppi, WSQ, wavelets

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1 Scope

The 1000ppi fingerprint JPEG 2000 profile and required content of the associated JP2 format are described in this document. The purpose for this profile is to:

- insure image quality
- insure interoperability including backward compatibility
- position criminal justice agencies to leverage commercial investment in open COTS solutions

This specification is applicable to 1000ppi continuous-tone gray-scale digital fingerprint images with a bit depth of 8 bits per pixel.

This specification

- specifies a file format for storing and transmitting compressed 1000ppi fingerprint image data
- specifies a class of encoders for converting source 1000ppi fingerprint image data to compressed image data
- specifies a class of decoders for converting compressed image data to reconstructed 1000ppi fingerprint image data
- specifies two classes of transcoders for converting between this compression specification and the FBI's compression spec for 500ppi fingerprints (WSQ)

For brevity, elements of this specification will be labeled as FP (1000ppi Fingerprint compression Profile). For example, references will be made to the FP JPEG 2000 codestream and the FP JP2 format.

All sections of this document are normative, unless explicitly labeled as informative.

2 References

The following Recommendations, Specifications and International Standards contain provisions that, through reference in this text, constitute provisions of this Specification.

1 ISO/IEC 646:1991, ISO 7-bit coded character set for information interchange.
2 ANSI/NIST-ITL 1-2000, NIST Special Publication 500-245, “American National Standard for Information Systems---Data Format for the Interchange of Fingerprint, Facial, & Scar Mark & Tattoo (SMT) Information,” 2000.
3 Criminal Justice Information Services (CJIS) WSQ Gray-scale Fingerprint Image Compression Specification, Federal Bureau of Investigation document No. IAFIS-IC-0110(V3), 19 Dec 1997.
4 ISO/IEC 15444-1:2000, JPEG 2000 Part 1: Image Coding System: Core Coding System.
5 ISO/IEC 15444-1:2000-Amd1, JPEG 2000 Part 1: Image Coding System: Core Coding System, Amendment 1.
6 ISO/IEC 15444-1:2000-Amd2, JPEG 2000 Part 1: Image Coding System: Core Coding System, Amendment 2.
7 ISO/IEC 15444-4:2002, JPEG 2000 Part 4: Image Coding System: Conformance
8 http://www.mitre.org/tech/mtf, Image Quality Measure (IQM)

3 Definitions

For the purposes of this Specification, the definitions shown in 15444-1 [4] Section 3 and the following apply.

transcoding: A process that converts one compressed format to another.

4 Abbreviations and Symbols

4.1 Abbreviations

For the purposes of this Specification, the following abbreviations apply.

bpp: bits per pixel
IEC: International Electrotechnical Commission
IQM: Image Quality Measure [8]
ISO: International Organization for Standardization
JPEG: Joint Photographic Experts Group. The joint ISO/ITU committee responsible for developing standards for continuous-tone still picture coding. It also refers to the standards produced by this committee.
ppi: pixels per inch
PCRL: Position-Component-Resolution-Layer
RLCP: Resolution-Layer-Component-Position
RPCL: Resolution-Position-Component-Layer
RMSE: Root Mean Square Error
WSQ: Wavelet Scalar Quantization [3]

4.2 Symbols

For the purposes of this Specification, the following symbols apply

'xyz': Denotes a character string, included in a field exactly as shown but without the beginning and ending quote marks.
0x---: Denotes a hexadecimal number
<CR>: A single carriage return character
<LF>: A single linefeed character
<SP>: A single space character (0x20 in hexadecimal)
COM: Comment marker
FP: Profile for 1000ppi Fingerprint Compression
POC: Progression order change marker

5 Introduction

This specification for storage of 1000ppi fingerprints (or like imagery such as palm- or footprints) is based upon JPEG 2000 compression.

Since JPEG2000 is an extremely broad compression standard, a specific profile for JPEG 2000 in JP2 format has been developed for fingerprint compression. The FP JP2 file can be used as a single file, or encapsulated in an ANSI NIST card file [2]. The FP JPEG 2000 profile and required content of the FP JP2 format are described in Sections 6 and 7.

In addition to the profile restrictions, Section 8 describes a set of compliance tests that ensure a minimal degree of quality for FP JPEG 2000 encoders and decoders. Applications may find it easier to pass the compliance tests if the JPEG 2000 parameter settings used in test development are followed to some extent. Guidelines for JPEG 2000 settings are provided in Section 7.3, but are not a requirement.

As well as testing JPEG 2000 encode/decode capabilities, the compliance suite tests the ability to convert a 1000ppi FP JPEG 2000 compressed file into a 500ppi WSQ file. This conversion, referred to as transcoding, requires an understanding of the WSQ standard [3].

6 JP2 File Format

JP2 is a file format that allows meta-data to be packaged with the image data, using a convention called ‘boxes’. Each box begins with an indication of box length and type, followed by the contents, which may be data or other boxes. Boxes contain logical groupings of meta-data or a compressed image codestream.

6.1 FP JP2 Profile

The JP2 specification [4] mentions mandatory, optional and customizable boxes.
The FP JP2 profile increases the list of mandatory boxes to include Capture Resolution.

A FP JP2 file must include the following:

- JPEG 2000 Signature box
- File Type box
- JP2 Header superbox containing:
  - Image Header box
  - Color Specification box (populated to indicate grayscale)
  - Resolution superbox containing Capture Resolution
- Contiguous Codestream box (using the FP JPEG 2000 profile)

Other optional boxes may appear in a FP JP2 file, but the above list is mandatory. An informative example of a minimal FP JP2 file is given in Appendix A.

7 JPEG 2000 Codestream

The JPEG 2000 standard [4] is very flexible, but the number of choices provided can be daunting when attempting to encode an image. To help create a useful interoperable system some additional limitations and guidance are provided. The limitations, called the FP JPEG 2000 Profile, are requirements for any 1000ppi fingerprint compression. The guidance, by contrast, is not a requirement but an aid to achieving parameter settings that are known to produce adequate image quality.

7.1 FP JPEG 2000 Profile

The FP JPEG 2000 fingerprint profile is an additional restriction within JPEG 2000 Profile 1 as defined in ISO 15444-1 Amd 1 [5]. Table 1 below shows the FP JPEG 2000 Profile Requirements (including Profile 1 limitations).

Table 1. Codestream Requirements for FP

Restrictions	***1000ppi Fingerprint Profile***
Profile 1 Requirements	
Profile Indication	Rsiz = 2 or 1 (minimal value appropriate)
Image Size	Xsiz, Ysiz < 2^{31}
Tiles	Multiple tiles: XTsiz/min($XRsiz^i$, $YRsiz^i$) ≤ 1024 XTsiz=YTsiz Or one tile for the whole image: YTsiz+YTOsiz>=Ysiz XTsiz+XTOsiz>=Xsiz
Image & tile origin	XOsiz, YOsiz, XTOsiz, YTOsiz < 2^{31}
Code-block size	xcb ≤ 6, ycb ≤ 6
RGN marker segment	SPrgn ≤ 37
Additional FP Requirements	
COM marker	Required COM marker indicating compression software version. See Section 7.1.1
Filter	9-7 irreversible
Levels of Decomposition	6
Number of components	1 for grayscale
Number of Layers	At least 9 layers at bitrates less than or equal to 0.55 bits per pixel. Suggestion: Include 0.55 bits per pixel to facilitate testing and some very low rates for low-resolution display.
Progression Order	Resolution based predominating layer order: RPCL, RLCP, or PCRL
Parsability	If a POC marker is present, the POC marker shall have RS_{POC}^0=0 and CS_{POC}^0=0.

7.1.1 FP COM Marker Segment

The FP profile number and software implementation must be identified using a 20-byte comment marker segment (COM) as specified in Table 2. The encoder may insert other COM markers at its discretion, but none of the other comments should have a Ccom string that begins 'EncID:'.

Table 2. Content of FP specified COM marker

Parameter	Size (bits)	Values	Notes
COM	16	0xFF64	Required for FP profile
Lcom	16	18	
Rcom	16	1	Ccom is ASCII character string
Ccom1	8*6	'EncID:'	Fixed string, Identifying this comment.
Ccom2	8*2	'1<SP>'	FP JPEG 2000 profile version number.
Ccom3	8*6	<softwareID>	Character string indicating software implementation that encoded this image. (Value assigned by the FP compliance testing body.)

7.2 FP JPEG 2000 Layers (informative)

The actual layer bitrates can be adjusted to meet specific program requirements. In order to have sufficient quality to allow transcoding to WSQ, the compression must contain a layer bound of at least 0.55 bpp (i.e., under 15:1 compression). Files with higher amounts of compression should not be transcoded to WSQ. To offset the cost of large file sizes, multiple layers (including some very low bitrates) should be included to facilitate progressive transmission at a variety of resolutions. If the total compression contains more than 0.55 bpp, then an encoder should include an intermediate layer at 0.55 bpp to facilitate testing.

7.3 FP JPEG 2000 Guidance (informative)

The FP profile for JPEG 2000 given in Section 7.1 is very broad and leaves a variety of coding alternatives unspecified. This flexibility is intentionally included to allow for future developments. However, to ensure reasonable image quality, there are compliance tests that levy an additional quality requirement that is not part of the JPEG 2000 standard. Therefore, not all JPEG 2000 codestreams that match this profile will be able to pass the quality-based certification tests. Table 3 enumerates the JPEG 2000 parameters that are used in the reference encoder, decoder, and transcoder. Implementations using these settings are more likely to pass the certification tests.

Table 3. JPEG 2000 Parameter Guidance

Parameter	Test Development Settings
Wavelet filter	9-7 irreversible *****
Levels of Decomposition	6 *****
Progression	RPCL
Layers	0.55 bpp, plus eight approximate bpp lower layers 0.35, 0.25, 0.15, 0.10, 0.06, 0.04, 0.025, 0.015
Image offset	0,0
Subsampling (X/YRsiz)	1,1
Components	1 *****
Bits per sample	8
Tiles	None
Tile parts per tile	1
Tile offset	0,0
Precincts	Max-size
Code blocks	64x64
Coding alternatives	
Bypass mode	No
Reset each pass	No
Terminate each pass	No
Vertical causal contexts	No
Predictable termination	No
Segmentation symbols	No
Optional Markers Present	None
Guard Bits	2
Quantization Format	Expounded
Implementation Bit Depth	32
ROI's (use of RGN)	None present
Reconstruction Bin Position	0.5

***** This parameter setting is required. See Table 1.

8 Compliance Testing

The syntax of FP JP2 files is determined by checking the presence/formatting of specific boxes/marker segments and validating that the file can be decoded with a reference decoder. Encoder, decoder, and transcoder tests are used to ensure that implementations perform coding operations accurately. In addition to the syntax and objective metric tests, visual confirmation is performed.

8.1 Syntax Tests

The presence and content of the mandatory box and marker segments will be checked within FP JP2 files. In addition the FP JPEG 2000 Profile parameter settings will be checked (Profile 1, 9-7 filter, progression order, LL size, etc)

Syntax Check Items
JPEG 2000 Signature box
File Type box
Image Header box
Color Specification box
Capture Resolution box
FP COM marker segment
Match Profile 1
9-7 irreversible filter
Progression order
components
levels of decomposition
layers
POC restrictions

The remainder of the syntax checking is achieved by validating that the file can be decoded without warning or error messages.

8.2 Visual Confirmation

FP compressed images must be of sufficient quality to allow for: (l) conclusive fingerprint comparisons (identification or non-identification decision); (2) fingerprint classification; (3) automatic feature detection; and (4) overall Automated Fingerprint Identification System (AFIS) search reliability.

Compression is not expected to eliminate defects present in the source image, but it should not introduce an abundance of visual defects. Test images shall be inspected for the addition of artifacts or anomalies such as, but not necessarily limited to, the following list. Visually detected anomalies or artifacts may be quantified to further establish their degree of severity.

- boundary artifacts between tiles or codeblocks
- wavelet artifacts
- blurring

8.3 Implementation Tests

Three types of implementations are tested: encoders, decoders, and transcoders. Most of the tests include the computation of a few image metrics to ensure that adequate quality is maintained for each type of processing. These tests are based upon a specific set of test inputs and reference images. This section describes the form of the tests and contains metric bounds that apply to three sample images (A, B, and D) available to application builders for pre-testing. Appendix B contains information relating to the computation of these image quality metrics, and Appendix C contains the full set of metric bounds invoked during compliance testing.

8.3.1 Encoder Compliance Tests

The encoding process generates a 1000ppi compressed file from the original 8-bit image. To ensure adequate quality, but still allow implementation flexibility in the future, testing of the encoding process will be based upon reconstructed image metrics rather than encoded wavelet coefficients. The metric thresholds are designed for a 0.55 bpp bitrate (i.e., 14.55:1 compression ratio).

For each reference 1000ppi image, the encoder under test will generate a test 1000ppi JP2 file. This test JP2 file will then be decoded using the reference decoder[1], to generate both a 1000ppi reconstruction and a 500ppi reconstruction. The test JP2 file and reconstructions will be compared to the corresponding reference JP2 (produced by a reference encoder) and the reference images, and must satisfy the following conditions.

1) The test JP2 file passes the syntax test.

2) The compressed JPEG 2000 codestream size (excluding any COM marker segments) produced by the implementation under test shall be no more than 0.1% larger than the target codestream size (0.55bpp). There is no lower limit on the codestream size. Only the size of contributions up to the layer closest to 0.55 bpp will be included in this test.

$$\frac{8S_T - 0.55N}{0.55N} 100 \leq 0.1$$

where S_T is the codestream size in bytes for the implementation under test and N is the number of pixels in the image.

3) The quality metrics of the 1000ppi reconstruction (at 0.55 bpp) shall conform to the bounds set out in Table C-1. Table 4 gives a small sample of the content of that table.

4) The quality metrics of the 500ppi reconstruction (using layers up to 0.55 bpp at the original resolution) shall conform to the bounds set out in Table C-2. Table 5 gives a small sample of the content of that table.

5) The test reconstructions are confirmed visually.

[1] The reference decoder used for this encoder test is JJ2000 v5.1 Available at http://jpeg2000.epfl.ch

Table 4. Sample Metric Bounds for 1000ppi Encoder Test

Original	1000ppi Reconstruction	RMSE (orig 1000, test 1000) is less than	IQM (test 1000ppi reconstruction) is greater than[2,3]
A.img	A.tst.1000.der	13.11	0.0268
B.img	B.tst.1000.der	9.656	0.0810
D.img	D.tst.1000.der	6.475	0.0092

Table 5. Sample Metric Bounds for 500ppi Encoder Test

Ref 500ppi	500ppi Reconstruction	RMSE (ref 500, test 500) is less than	IQM (test 500ppi reconstruction) is greater than[3,4]
A_500.img	A.tst.500.der	7.285	0.0117
B_500.img	B.tst.500.der	5.658	0.0360
D_500.img	D.tst.500.der	3.975	0.0039

8.3.2 Decoder Compliance Tests

Decoders must not only be able to decode FP JP2 files to sufficient quality, but also demonstrate ability to decode any JPEG 2000 Profile 1 codestream and any grayscale JP2 file.

1) The implementation under test has demonstrated JPEG2000 conformance [7] for Profile 1 Cclass 1 and JP2 grayscale.
2) The implementation under test shall decode each test input FP JP2 file fully and the resultant 8-bit image will be compared to a reference 1000ppi image. The quality metrics of the 1000ppi reconstruction shall conform to the bounds set out in Table C-3. Table 6 gives a small sample of the content of that table.

Table 6. Sample Metric Bounds for Decoder Compliance Test

Original	Test Image	RMSE (orig 1000, test 1000) is less than	IQM (test 1000ppi reconstruction) is greater than[2,3]
A.img	A.jp2.1000.dec	12.76	0.0258
B.img	B.jp2.1000.dec	9.37	0.0786
D.img	D.jp2.1000.dec	6.20	0.0090

3) The test reconstructions are confirmed visually.

[2] For 1000ppi reconstructions the threshold values in these tables are at least 73% of the original image IQM. The proportion of original image quality maintained varies with image content.
[3] See Appendix B for IQM preferences and auxiliary file contents required for these tests.
[4] For 500ppi reconstructions the threshold values in this table are at least 95% of the reference 500ppi image IQM.

8.3.3 Transcoder Compliance Tests

The transcoding process is used to create a 500ppi WSQ file from a FP JP2 file. Various implementation avenues exist, but they will all use some portion of a JPEG2000 decoder along with a WSQ encoder. Two alternative tests are available.

1) If the transcoder is separable into two segments with an 8-bit character image as a result of the JPEG 2000 decoder segment, then transcoder test A is applied.
2) If the JPEG 2000 decoder section uses a reconstruction factor of 0.5 and passes floating-point data to the WSQ encoder, then transcoder test B is applied.

8.3.3.1 Transcoder Test A

The 8-bit image that is created by the JPEG 2000 decoder segment must be made available for testing. In addition, it must be possible to test the WSQ encoder implementation with inputs that are not derived from the JPEG 2000 decoder. Transcoder test A is then broken into two segments: a JPEG 2000 transcoder decoding test, and the WSQ encoder compliance test described in [3].

The JPEG 2000 transcoder decoding test is described here. For each test input FP JP2 file, the implementation under test will generate the 500ppi 8-bit image that would be passed to the WSQ encoder segment. This is called the test reconstruction. The test reconstruction will be compared to a reference 500ppi reconstruction. [The reference reconstruction is created using the reference JP2 decoder.]

The difference between the test reconstruction and the reference 500ppi reconstruction at any pixel shall be at most 1 gray level. The absolute value of the mean error and the mean absolute error between the test reconstruction and the reference 500ppi reconstruction shall be no more than the values set out in Table C-4. Table 7 gives a small sample of the content of that table. [The tolerances in this test are unlikely to be met without using a 0.5 reconstruction factor and greater than 16-bit implementation precision.]

Table 7. Sample Metric Bounds for Transcoder Test A

Reference	Test Image	Mean Absolute Error	|Mean Error|
A.der	A.jp2.500.dec	0.01	0.005
B.der	B.jp2.500.dec	0.01	0.005
D.der	D.jp2.500.dec	0.01	0.005

Transcoder Test A is not complete until the WSQ encoder compliance is also tested [3].

8.3.3.2 Transcoder Test B

Transcoder compliance test B is nearly identical to the WSQ encoder compliance test, with the transcoder being tested as a single unit.

For each test input FP JP2 file, the transcoder will generate a 500ppi test WSQ file. The test WSQ file will be compared to the corresponding reference WSQ file and must meet the following conditions:

1) It is a correctly formatted WSQ fingerprint file.

2) The compressed file size (excluding comments) produced by the implementation under test shall be within 0.4% of the reference compressed file size.

$$\frac{|S_T - S_R|}{S_R} 100 \le 0.4$$

where S_T and S_R are the file size for the implementation under test and the reference WSQ file respectively.

3) All quantization bin widths (including the zero bins) shall be within 0.051% of the corresponding bin widths contained in the quantization table within the reference compressed image.

$$\frac{|Q_{k,T} - Q_{k,R}|}{Q_{k,R}} 100 \le 0.051 \quad \text{and} \quad \frac{|Z_{k,T} - Z_{k,R}|}{Z_{k,R}} 100 \le 0.051 \quad 0 \le k \le 59$$

where $Q_{k,R}$ and $Q_{k,T}$ are the quantization bin widths for the kth subband in the reference and test WSQ files respectively. $Z_{k,R}$ and $Z_{k,T}$ are the corresponding zero bin widths.

4) At least 99.99% of the bin index values, $p_k(m,n)$, within the test implementation WSQ file shall be the same as the corresponding values in the reference WSQ file and no bin index value shall differ by more than 1.

8.3.4 Test Data

The following test data and information can be obtained by contacting the cognizant government office:

Federal Bureau of Investigation,
Systems Engineering Unit, CJIS Division
(Attn: Tom Hopper, Room 11192E)
935 Pennsylvania Avenue, N.W.
Washington, D.C. 20537-9700
Telephone (voice): (202) 324-3506
Telephone (fax): (202) 324-8826
Email: thopper@leo.gov

- Sample test images, codestreams, and image metric bounds for compliance testing, such as those shown in the tables in Section 8.3.1 through Section 8.3.3. [Note: MITRE has prepared a CD containing this data.]
- Issuance of FP COM marker SoftwareIDs.
- Information on formal compliance certification with comprehensive test set.

Appendix A Minimal FP JP2 Example (Informative)

Although the JP2 format is fully described in ISO 15444-1, this annex provides an informative example of a minimum content FP JP2 file for the sake of clarity. This example is not normative, since additional meta-data may appear in FP JP2 files. A JP2 decoder will be able to interpret data from any valid JP2 file.

A JP2 file is constructed of information containers called boxes. Each box begins with an indication of box length and type, followed by the contents, which may be other boxes. Boxes contain logical groupings of meta-data or a compressed image codestream.

The minimal FP content of each box is described in the following sections. For further information about box content and the different box representations in this appendix see ISO 15444-1 [4].

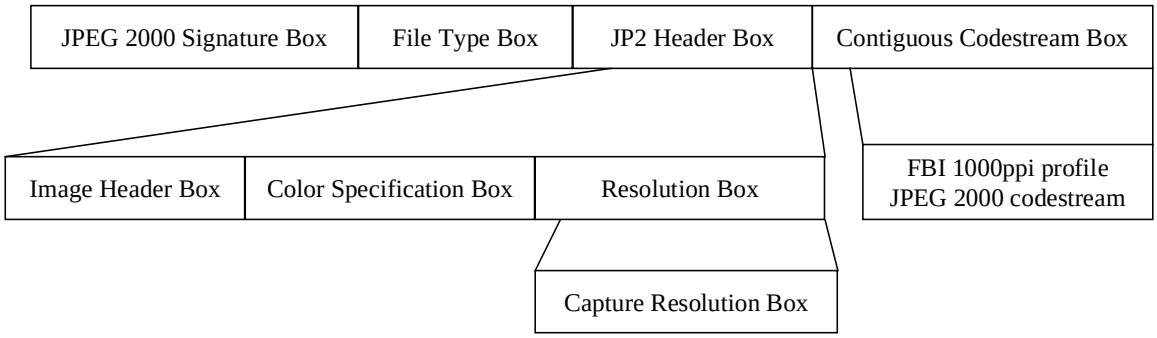

Figure A-1. High-level FP JP2 Mandatory Content

A.1 JPEG 2000 Signature Box

The JPEG 2000 Signature box has the following format and contents.

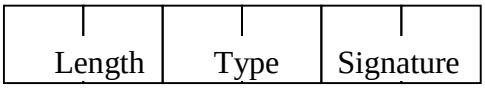

Figure A-2. Organization of the JPEG 2000 Signature Box

The Type field is written using ISO 646 [1] (ASCII) and includes the space character, denoted <SP>. In hexadecimal, a correctly formed JPEG 2000 signature box will read 0x0000 000C 6A50 2020 0D0A 870A.

Field	Value	Size (bytes)	Hexadecimal
Length	12	4	0000 000C
Type	‘jP<SP><SP>’	4	6A50 2020
Signature	‘<CR><LF><0x87><LF>’	4	0D0A 870A

Figure A-3. Contents of the JPEG 2000 Signature Box

A.2 File Type Box

A minimal FP JP2 file type box has the following contents. More complex versions of this box are possible, but not required for encoders. Decoders shall be able to properly interpret any JP2 file type box. See ISO 15444-1 for a complete description of this box, and what additional options are available.

Figure A-4. Organization of the File Type Box

Field	Value	Size(bytes)	Hexadecimal
Length	20	4	0000 0014
Type	'ftyp'	4	6674 7970
Brand	'jp2<SP>'	4	6A70 3220
Minor Version	0	4	0000 0000
CL	'jp2<SP>'	4	6A70 3220

Figure A-5. Contents of the File Type Box

A.3 JP2 Header Box

A minimal FP JP2 Header box is a superbox with the following format and contents. More complex versions of this box are possible, but not required for encoders. Decoders shall be able to properly interpret any JP2 file type box. See ISO 15444-1 for a complete description of this box, and what additional options are available.

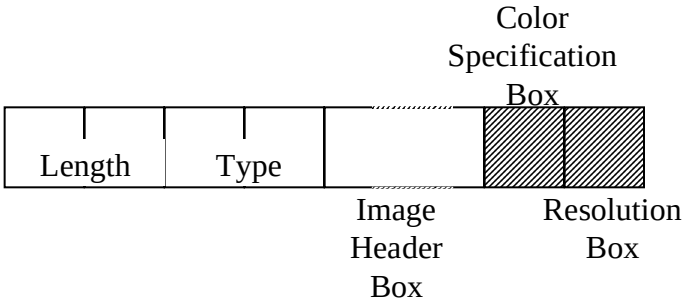

Figure A-6. Organization of the JP2 Header Box

Field	Value	Size (bytes)	Hexadecimal
Length	71	4	0000 0047
Type	'jp2h'	4	6A70 3268

Figure A-7. Contents of the JP2 Header Box

A.3.1 Image Header Box

The Image Header box has the following format and contents.

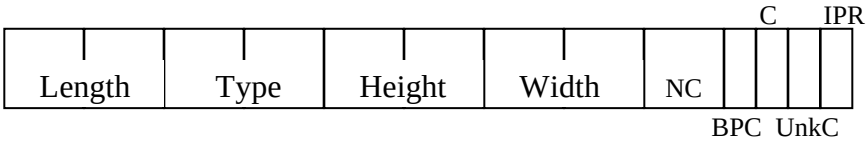

Figure A-8. Organization of the Image Header Box

Field	Value	Size (bytes)	Hexadecimal
Length	22	4	0000 0016
Type	'ihdr'	4	6968 6472
Height	Ysiz-YOsiz	4	
Width	Xsiz-XOsiz	4	
NC (# components)	1	2	0001
BPC (bit depth minus one and sign of all components)	7	1	07
C (compression type)	7	1	07
Unknown Colorspace Flag	0	1	00
IPR	0	1	00

Figure A-9. Contents of the Image Header Box

A.3.2 Color Specification Box

The Color Specification box has the following format and contents for a grayscale fingerprint. If color data is allowed in the future, then see ISO 15444-1 for a complete description of alternatives available for color.

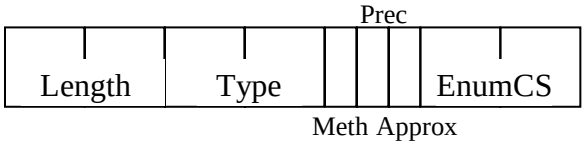

Figure A-10. Organization of the Color Specification Box

Field	Value	Size (bytes)	Hexadecimal
Length	15	4	0000 000F
Type	'colr'	4	636F 6C72
Method	1	1	01
Precedence	0	1	00
Approximation	0	1	00
Enumerated Colorspace	17 (= grayscale)	4	0000 0011

Figure A-11. Contents of the Color Specification Box

A.3.3 Resolution Box

A minimal FP Resolution box is a superbox with the following format and contents. The presence of this box is mandatory for FP JP2 files. More complex versions of this box are possible, but not required for FP encoders. Decoders shall be able to properly interpret any resolution box. See ISO 15444-1 for a complete description of this box, and what additional options are available. [If this format is used for fingerprints at resolutions different from 1000ppi, then the Capture Resolution fields must be modified to indicate the appropriate resolution.]

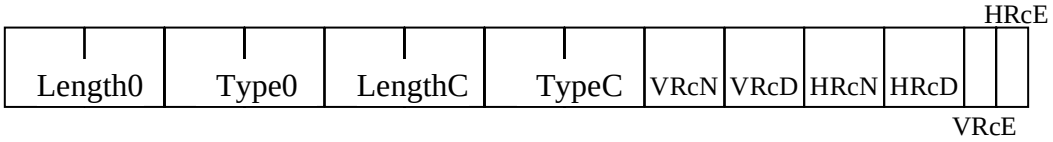

Figure A-12. Organization of the Resolution Box

Field	Value	Size (bytes)	Hexadecimal
Length0	26	4	0000 001A
Type0	'res<SP>'	4	7265 7320
Length Capture Res	18	4	0000 0012
Type Capture Res	'resc'	4	7265 7363
VRcN (pixels / meter)	39370	2	99CA
VRcD	1	2	0001
HRcN (pixels / meter)	39370	2	99CA
HRcD	1	2	0001
VRcE	0	1	00
HRcE	0	1	00

Figure A-13. Contents of the Resolution Box (indicating a capture resolution of 1000ppi)

A.4 Contiguous Codestream Box

The contiguous codestream box consists of the box length and type indications followed by a JPEG 2000 codestream.

Figure A-14. Organization of the Contiguous Codestream Box

Field	Value	Size (bytes)	Hexadecimal
Length	Codestream length +8	4	
Type	'jp2c'	4	6A70 3263

Figure A-15. Contents of the Contiguous Codestream Box

Appendix B Quality Metrics

There is no single image metric that is known to exactly match human perception of image quality. Instead a variety of metrics are used in the literature to test various aspects of image 'quality.' Several of them are used for the purposes of FP compliance testing.

B.1 Comparative Image Metrics

Many image metrics compare a test image against a fixed reference. RMSE, Mean Absolute Error, and Absolute Mean Error are all of this type. In each of these metrics a difference is computed between the gray values in the two images at each of the *N* pixel positions, and then the resulting difference image is incorporated into a particular formula.

B.1.1 Root Mean Square Error (RMSE)

The root mean square error is computed using the following formula:

$$RMSE(reference, test) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(test_i - reference_i)^2}$$

Where $test_i$ and $reference_i$ are gray values in the corresponding images at pixel position *i*. The sum is computed over all (*N*) pixel positions.

B.1.2 Mean Absolute Error

The mean absolute error is computed using the following formula:

$$MeanAbsoluteError = \frac{1}{N}\sum_{i=1}^{N}\left|test_i - reference_i\right|$$

When the maximum difference between two images is less than or equal to one, the mean absolute error becomes a measure of the number of image pixels which vary between the test and reference image.

B.1.3 Absolute Mean Error

The absolute mean error is computed using the following formula:

$$\left|MeanError\right| = \left|\frac{1}{N}\sum_{i=1}^{N}\left(test_i - reference_i\right)\right|$$

A large absolute mean error is indicative of an overall shift in image brightness, with the test image either brighter or darker than the reference image.

B.2 Single-Image Metrics

In contrast to a comparative image metric, a single-image metric only relies upon data from the test image itself. The goal of this type of metric is to give a sense of image quality without reference to another image.

B.2.1 Image Quality Measure (IQM)

IQM is a single-image quality metric. An executable implementation, a user's guide, and a paper describing IQM in more detail, can be found at: http://www.mitre.org/tech/mtf

The IQM code requires 3 input files to run:

image file
auxiliary data pertaining to the image (auxdatafile)
preferences file that specifies IQM run parameters (prefsfile)

IQM is computed using the following formula (eq.14 in Opt.Eng. paper at above website):

$$\mathrm{IQM} = \frac{1}{\mathrm{M}^2} \sum_{\theta=-180^0}^{180^0} \sum_{\rho=0.01}^{0.707} \mathrm{S}(\theta_1)\mathrm{W}(\rho)\mathrm{A}^2(\mathrm{T}\rho)\mathrm{P}(\rho,\theta)$$

For the specific application to fingerprints in this document, the parameters in the above formula have the following values:

M = number of pixels across width of square image to which IQM is applied (specified in auxdatafile)

$S(\theta_1) = 1.0$ when specifying sensor #4 in auxdatafile

$W(\rho) = 1.0$ with the noise-related parameter values defined in the default prefsfile, IQM should compute a value of 1.0 for W(ρ); if it computes a different value, signified by "problem code" 5 or 6 appearing in IQM output file it implies the fingerprint image is far off-the-mark, e.g., very noisy

$A(T\rho)$ = visual response modulation transfer function, with peak of MTF set to 0.5 cy/ pixelwidth when using default prefsfile values: spot=0.6, viewdist=351.3288 (T=internal constant)

$P(\rho,\theta)$ = power spectrum of image, normalized by zero frequency power (in default prefsfile: psntype=DC)

ρ = radial spatial frequency in units of cycles per pixelwidth; lower & upper limits defined in default prefsfile (freqmin=0.01, freqmax=0.707107); p_{max} is bounded by maximum cartesian coordinate values: $x_{max}=y_{max}=0.50$

θ = angle around the two-dimensional power spectrum

For 8 bpp images, IQM expects pure white in the image to be gray level 255. The user should always verify that the polarity of the images, in combination with the polarity parameter value set in the auxdatafile, either "L" or "B", results in IQM reading a near-white area of the image as near gray level 255, and a near-black area as near gray level 0.

This can be verified for an individual image by noting the gray levels for 4 pixels displayed during IQM runtime, or the gray level for 1 pixel printed to the output file, and comparing to what is known to be correct for the given image, in the given pixel locations. [For more details, see IQM_Guide, section 3-Image Formats.]

The IQM computation is only applied to square image areas. The location and size of this square area for each input image is part of the auxdatafile. The auxdatafile used on reconstructed images for encoder and decoder tests based on sample test image A is given in Figure B-1[5] (the IQM executable can automatically generate this file via interactive user input). Figure B-2 shows an example of how IQM interprets this auxdatafile.

```
# AuxDataFile TEMPLATE for IQM run of Fingerprint Images @ 1000ppi & 500ppi
# Use with IQM's DefaultPrefsFile
# IQM is applied to square subimage in each case; subimage size is dependent on image
# Subimage width for 500ppi image is always 1/2 of subimage width for corresponding 1000ppi image
#  All cases: sensor 4,  mag=1.0 for 1000ppi image,  mag=0.5 for 500ppi image
# User should Always verify polarity (L or B) of actual images, as read by IQM on his/her computer !

 A.tst.1000.der.pgm      GRAY            1000ppi reference reconstruction for encoder test
  0  0  0  8 L  0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    0.0     0.0     0.0     0.0  4 0  1.000
   72    56  1024

A.tst.500.der.pgm       GRAY            500ppi reference reconstruction for encoder test
   0  0  0   8 L  0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    0.0     0.0     0.0     0.0  4 0  0.500
   36  28  512

A.jp2.1000.dec.pgm      GRAY            1000ppi reconstruction for decoder test
  0  0  0  8 L  0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0    0.0     0.0     0.0     0.0  4 0  1.000
   72    56  1024
```

Figure B-1. AuxdataFile Content for Image A

The sample B and D images repeat this pattern, with differences only in the final line denoting the horizontal and vertical pixel offset and size of the square subimage to which the IQM is applied. The final lines for B and D are:

B 1000ppi: 144 68 900
B 500ppi 72 34 450
D 1000ppi: 37 39 800
D 500ppi: 19 20 400

[5] The auxdatafile is free format, using spaces to separate inputs. Line breaks must occur as shown.

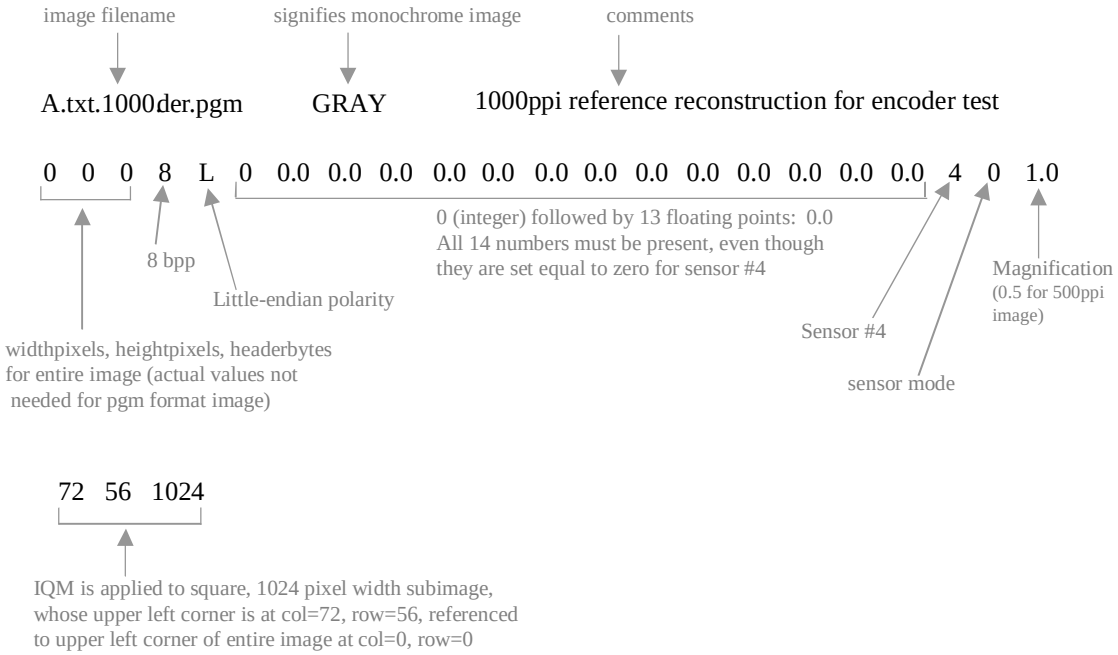

Figure B-2. Example of IQM Interpretation of the AuxdataFile

Appendix C Metric Bounds

This appendix contains the full tables of metric bounds used for the compliance tests described in Section 8.3. This information is provided for use by a testing agency with access to the reference imagery. Tables in Section 8.3 contain bounds for sample data and reference imagery provided to application builders.

C.1 Notation

The following key may be helpful in interpreting the table content.

Original	Original 1000ppi image prior to any compression
Ref 500ppi	500ppi version of the original image. Created using the 9-7 irreversible JPEG 2000 transform, rounded back to 8-bit integers without any other quantization
Reference	Image used as a basis for comparison. Not necessarily the original
Col 1	Column 1 entry
Col 2	Column 2 entry
*.der	An image created with the reference decoder The reference decoder used for this encoder test is JJ2000 v5.1 Available at http://jj2000.epfl.ch
*.dec	Decoded image created by the product under test
*.jp2	An FP JP2 provided as test input
*.tst	An FP JP2 created by encoder software under test
.1000.	A full resolution decode
.500.	A half resolution decode

For encoder compliance, the software under test will create *.tst files. The testing organization will then decode these files both at full resolution and at half resolution using the reference decoder to generate *.tst.1000.der and *.tst.500.der.

For decoder compliance, the software under test will fully decode the *jp2 files to create *.jp2.1000.dec images.

For transcoder compliance test A, the software under test will perform a half resolution decode to generate *.jp2.500.dec images.

These output *.der or *.dec images are compared to the appropriate reference images shown in the first column of the testing tables shown here.

C.2 Metric Bounds Tables

The metrics contained in these tables (RMSE, Mean Absolute Error, Absolute Mean Error and IQM) are described in Appendix B . See Appendix B.2.1 for details on the preferences and auxiliary data required to compute IQM. The only IQM parameters which vary by image content across the compliance tests are horizontal and vertical pixel offset and size for the square subimage to which IQM is applied. The IQM Parameters column indicates the offset and size values required for those tests.

Table C-1. Metric Bounds for 1000ppi Encoder Test

Original	1000ppi Reconstruction	RMSE(Col 1,Col2) is less than	IQM Parameters	IQM (Col 2) is greater than
A.img	A.tst.1000.der	13.11	72 56 1024	0.0268
B.img	B.tst.1000.der	9.656	144 68 900	0.0810
D.img	D.tst.1000.der	6.475	37 39 800	0.0092
enc001.img	enc001.tst.1000.der	7.61	366 340 800	0.0346
enc002.img	enc002.tst.1000.der	4.76	290 534 700	0.0028
enc003.img	enc003.tst.1000.der	5.22	754 666 600	0.0466
enc004.img	enc004.tst.1000.der	6.06	64 322 460	0.0392
enc005.img	enc005.tst.1000.der	6.53	116 274 680	0.0108
enc006.img	enc006.tst.1000.der	6.44	362 666 500	0.1050

Table C-2. Metric Bounds for 500ppi Encoder Test

Ref 500ppi	500ppi Reconstruction	RMSE(Col 1,Col 2) is less than	IQM Parameters	IQM (Col2) is greater than
A_500.img	A.tst.500.der	7.285	36 28 512	0.0117
B_500.img	B.tst.500.der	5.658	72 34 450	0.0360
D_500.img	D.tst.500.der	3.975	19 20 400	0.0039
enc001_500.img	enc001.tst.500.der	3.79	183 170 400	0.0143
enc002_500.img	enc002.tst.500.der	2.73	145 267 350	0.00123
enc003_500.img	enc003.tst.500.der	3.07	377 333 300	0.0206
enc004_500.img	enc004.tst.500.der	3.48	32 161 230	0.0176
enc005_500.img	enc005.tst.500.der	3.83	58 137 340	0.00488
enc006_500.img	enc006.tst.500.der	3.93	181 333 250	0.0483

Table C-3. Metric Bounds for Decoder Compliance Test

Original	Test Image	RMSE(Col1,Col2) is less than	IQM Parameters	IQM (Col2) is greater than
A.img	A.jp2.1000.dec	12.76	72 56 1024	0.0258
B.img	B.jp2.1000.dec	9.37	144 68 900	0.0786
D.img	D.jp2.1000.dec	6.20	37 39 800	0.0090
dec001.img	dec001.jp2.1000.dec	4.052	622 348 700	0.0146
dec002.img	dec002.jp2.1000.dec	4.442	420 378 800	0.00642
dec003.img	dec003.jp2.1000.dec	4.532	386 470 680	0.00326
dec004.img	dec004.jp2.1000.dec	2.998	334 860 460	0.0408
dec005.img	dec005.jp2.1000.dec	3.916	366 652 680	0.00601
dec006.img	dec006.jp2.1000.dec	5.436	550 590 600	0.0455

Table C-4. Metric Bounds for Transcoder Test A

Reference	Test Image	Mean Absolute Error	|Mean Error|
A.der	A.jp2.500.dec	0.01	0.005
B.der	B.jp2.500.dec	0.01	0.005
D.der	D.jp2.500.dec	0.01	0.005
tns001.der	tns001.jp2.500.dec	0.01	0.005
tns002.der	tns002.jp2.500.dec	0.01	0.005
tns003.der	tns003.jp2.500.dec	0.01	0.005
tns004.der	tns004.jp2.500.dec	0.01	0.005
tns005.der	tns005.jp2.500.dec	0.01	0.005
tns006.der	tns006.jp2.500.dec	0.01	0.005