NIST Special Publication 500-289

Compression Guidance for 1000 ppi Friction Ridge Imagery

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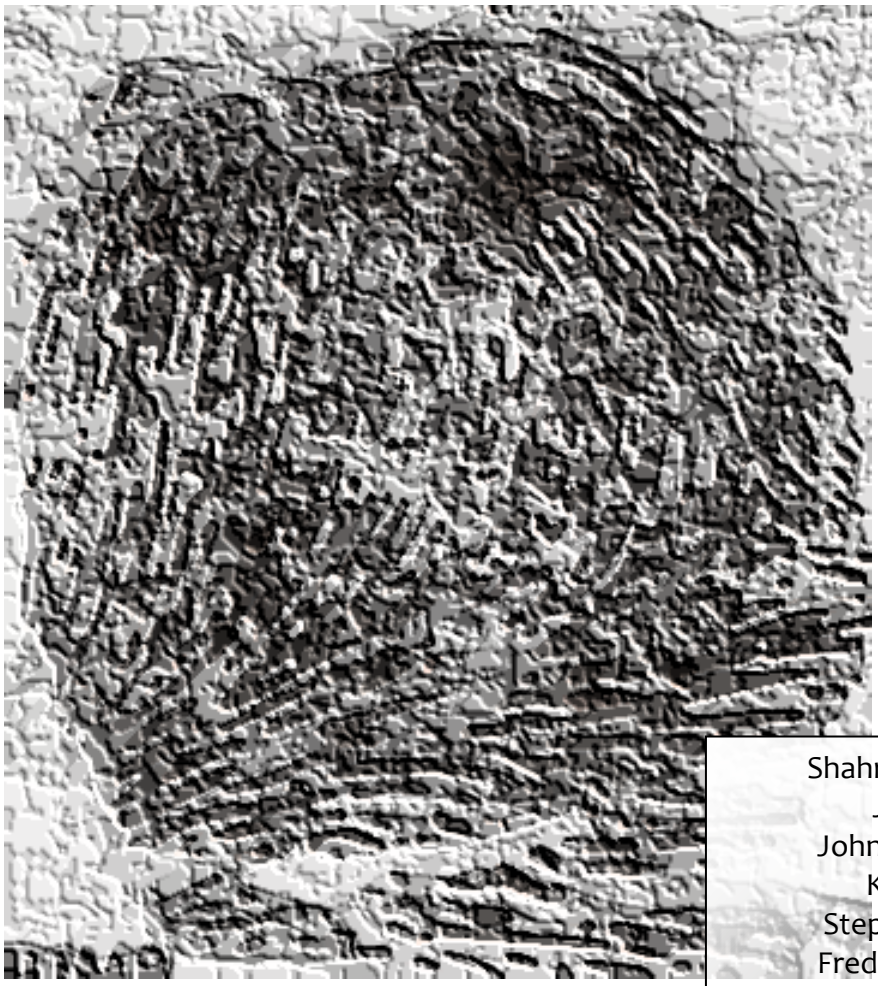

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EXECUTIVE SUMMARY

The criminal justice community has traditionally exchanged and stored fingerprint imagery data at 500 pixels per inch[1] (ppi) or 19.7 pixels per millimeter (ppmm). The Wavelet Scalar Quantization (WSQ) fingerprint image compression algorithm is currently the standard for the lossy compression of 500 ppi fingerprint imagery. The WSQ Gray-Scale Fingerprint Image Compression Specification [WSQ] provides guidance based on an International Association for Identification (IAI) study [FITZPATRICK] to establish the acceptable amount of fidelity loss due to lossy compression in order for a WSQ encoder and decoder to meet FBI certifications. These certifications are designed to ensure adherence to the WSQ specification and thereby to ensure fidelity and admissibility as forensic evidence of images that have been processed by such encoders and decoders.

Modern biometric systems are now trending towards the capture, transfer and storage of fingerprint images at 1000 ppi or 39.4 ppmm which offers many benefits, notably greater fidelity and better representation of Level 3 features[2]. The ANSI/NIST ITL and ISO 19794 standards require compression of 1000 ppi fingerprint imagery using the JPEG2000 algorithm rather than WSQ. Also, as systems transition to 1000 ppi, some systems will unavoidably contain an overlap between 500 ppi and 1000 ppi operational pathways. In addition to the adoption of JPEG2000, the overlap of and 1000 ppi operational data will also require an interoperability bridge between traditional 500 ppi and modern 1000 ppi data.

This special publication provides guidance for compression of 1000 ppi friction ridge imagery as well as an interoperability pathway between 500 ppi friction ridge imagery and new 1000 ppi friction ridge image data.

[1] Resolution values for friction ridge imagery are specified in pixels per inch (ppi) throughout this document. This is based on widely used specification guidelines for such imagery and is accepted as common nomenclature within the industry. SI units for these will be presented only once.

[2] The commonly accepted nomenclature defines Level 1 fingerprint details as the overall friction ridge pattern and flow, Level 2 detail as classic Galton features [GALTON] like minutiae points, and Level 3 as pores, creases, line shapes, incipient ridges and other non Level 1 or 2 features [JAIN].

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TERMS AND DEFINITIONS

The abbreviations and acronyms of Table 1 are used in many parts of this document.

Table 1 - Abbreviations

ANSI/NIST ITL	ANSI/NIST-ITL 1-2011, NIST Special Publication 500-290: Data Format for the Interchange of Fingerprint, Facial & Other Biometric Information
bpp	Bits per pixel
CODEC	Coder-Decoder
FBI	Federal Bureau of Investigation
IAFIS	Integrated Automated Fingerprint Identification System
IAI	International Association for Identification
JPEG	Joint Photographic Experts Group - ISO/IEC committee developing standards for image compression
JP2	JPEG2000 File Format Extension
NBIS	NIST Biometric Image Software
NGI	Next Generation Identification
NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards and Technology Interagency Report
PIV	Personal Identity Verification
ppi	Pixels per inch
ppmm	Pixels per millimeter
WSQ	The Wavelet Scalar Quantization algorithm for compression of fingerprint imagery

KEYWORDS

500 ppi; 1000 ppi; friction ridge imagery; downsampling; fingerprint compression; transcoding

1. Introduction

This special publication documents the JPEG2000 file and codestream profiles for use in the creation and interchange of fingerprint (friction ridge) data according to the ANSI/NIST-ITL 1-2011 standard [AN2k11] by law enforcement, criminal justice agencies, and other organizations that process fingerprint friction ridge data at a resolution of 1000ppi.

This special publication was prepared by the National Institute of Standards and Technology (NIST) in conjunction with the Federal Bureau of Investigation's (FBI) Criminal Justice Information Services Division (CJIS).

1.1. Background

The criminal justice community has traditionally captured, processed, stored and exchanged friction ridge imagery data at 500 ppi in the course of their operation. Modern biometric systems are trending towards operation on fingerprint images at 1000 ppi. This transition to 1000 ppi friction ridge imagery offers many benefits, notably greater fidelity to the original sample and better representation of Level 3 features[3]. Both of these benefits are favorable since they may increase probability of establishing a match/non-match decision by expert examiners or automated fingerprint matchers.

The JPEG2000 compression standard offers much flexibility in the types of images it can operate on as well as the way images can be compressed and encoded. This flexibility makes it a suitable compression algorithm for friction ridge imagery. While this flexibility can offer many operational benefits, this flexibility offers many degrees of freedom that can create potential compatibility issues across the various stakeholders hindering interoperability between those stakeholders. Because of this, a need exists for a normative guidance that establishes a set of protocols for the compression of images by stakeholders. Adherence to this normative guidance by stakeholders provides assurances for compatibility between those stakeholders. This special publication provides this normative guidance for compression of grayscale friction ridge imagery at 1000 ppi.

The transition to 1000 ppi systems will also unavoidably contain an overlap between 500 ppi and 1000 ppi operational pathways for various reasons. Some stakeholders may simply continue to operate at 500 ppi due to technical, financial or logistical reasons. Additionally, there will still be a need to compare newly collected 1000 ppi images against traditional 500 ppi images already in storage, for both one-to-one and one-to-many scenarios. This special publication also provides a normative guidance for the downsampling of 1000 ppi images so that they can be processed by 500 ppi systems.

2. Scope and Applicability

This guidance applies to compression and decompression algorithms designed to operate on gray-scale friction ridge imagery compressed in accordance with this special publication for maintaining the utility of compressed fingerprint images for forensic identification purposes. The scope and applicability of this guidance is limited to those images and this guidance is not intended to apply to compression of image content other than fingerprints.

[3] The commonly accepted nomenclature defines Level 1 fingerprint details as the overall friction ridge pattern and flow, Level 2 detail as classic Galton features [GALTON] like minutiae points, and Level 3 as pores, creases, line shapes, incipient ridges and other non Level 1 or 2 features [JAIN].

3. Purpose

The purpose of this special publication is to provide guidance for both the lossy and lossless compression of 1000 ppi grayscale fingerprint images as well as the downsampling of the resulting 1000 ppi JPEG2000 friction ridge imagery to 500 ppi in support of traditional systems and applications. The guidance is derived from a series of studies conducted by NIST to support the conclusions of this special publication. The studies that form the basis of this guidance include:

- NISTIR 7778: This study examines the response of trained fingerprint examiners to fingerprint images compressed using JPEG2000 at a range of compression ratios in order to determine an operational compression ratio for the JPEG2000 CODEC (Coder-Decoder) that approximates the threshold quality level expected of WSQ-compressed images for identification by trained examiners.
- NISTIR 7779: This study examines various algorithms for lossless compression of 1000 ppi fingerprint images with respect to the compression-performance (compression ratio) achieved as well as the throughput-performance of the examined algorithms with respect to both encoding and decoding operations.
- NISTIR 7780: This study examines the impact of JPEG 2000 lossy compression on 1000 ppi exemplar fingerprint imagery used in establishing an identity decision with an associated 1000 ppi latent fingerprint. The impact of compression on both Galton and non-Galton based features of a fingerprint are measured by expert latent fingerprint examiners.
- NISTIR 7781: This study provides a fundamental comparison of WSQ to JPEG2000 with respect to image fidelity of WSQ and JPEG2000 algorithms under operational compression levels as well as extreme compression levels. As WSQ is not designed or intended for use on 1000 ppi imagery, the comparison between the two algorithms was made using 500 ppi imagery where both WSQ and JPEG2000 were within their operational capabilities.
- NISTIR 7839: This study examines several methods of downsampling for the purpose of converting 1000 ppi fingerprint images to 500 ppi to allow 1000 ppi imagery to be operated on by traditional 500ppi systems.
- NISTIR 7939: This study examines effects of various JPEG2000 encoding options on image fidelity. Specifically, it examines various numbers of wavelet decomposition levels and quality layers.

4. Compression Guidance

Based on supporting data from the studies identified in section 3, this compression guidance recommends lossless compression of latent imagery using the JPEG2000 reversible filter, and lossy 10:1 compression with JPEG2000 for other impression types at 1000 ppi according to the parameters provided in this section.

4.1. JPEG2000 Codestream Parameters for Compression of 1000 ppi Imagery

The JPEG2000 CODEC shall be implemented according to ISO 15444-1 [JPEG2k] with the parameters shown below in Table 2 and used in the application of compression to friction ridge imagery captured at a resolution of 1000 ppi. The JPEG2000 format provides a container for metadata and a compressed data stream. In addition to the default superboxes[4], a comment box shall be implemented bearing certification and identification information according to Table 4. It should be noted that only implementation of Part-1 of the JPEG2000 standard [JPEG2k] is supported for this guidance.

Table 2 - JPEG2000 Contiguous Codestream Box Parameters

Parameter	Value (By Impression Type)	
	Rolled, Flat, Slap (Card scan, Live scan, Mobile ID and Palm)	Latent
Image and Tile Size (SIZ) Marker Segment		
Profile Indication	Rsiz = 2 (Profile-1)	
Maximum Image Size[5]	Xsiz, Ysiz < 2^{31}	
Tiles	One tile for the whole image: YTsiz + YTOsiz >= Ysiz XTsiz + XTOsiz >= Xsiz	
Number of Components	Csiz = 1	
Bit depth	Ssiz = 7 (corresponding to 8-bit Gray Scale)	
Subsampling	XRsiz = YRsiz = 1	
Markers/Locations	Coding Style Default (COD) and Quantization Default (QCD) Markers in Main Header Only	
Coding Style Default (COD) and Coding Style Component (COC) Markers		
Progression order[6]	Resolution-Position-Component-Layer (RPCL)	
Number of Wavelet Decomposition Levels[7]	$N_L = 6$	
Code block Size	xcb = 6, ycb = 6 (64x64)	
Code block style	SPcod and SPcoc = 0000 0000 (No selective arithmetic coding bypass)	
Transformation Filter Type	9-7 (Irreversible)	5-3 (Reversible)
Quality Layers	6 Either {10:1, 15:1, 20:1, 30:1, 40:1, 60:1, 80:1} or (in bpp) {0.8, 0.53. 0.4, 0.27, 0.2, 0.13, 0.1}	NA
Other Requirements		
Encoder ID and Capability box	Yes	
Resolution Box	Yes	
Final Compression Ratio / top quality layer	10:1	1:1 (Lossless)

[4] A box is defined in [JPEG2k] as a data segment of specified size and content. The box can contain other boxes. A box whose content consists only of other boxes is called a "superbox".

[5] Maximum image size supported will differ from the maximum allowable sizes for a given impression according to [AN2k11]. For further information on allowable image sizes please refer to section 5.2.

[6] See section 5.6 for more information.

[7] See section 5.4 for more information.

4.2. JP2 File Parameters

In a JPEG2000 friction ridge production file, the codestream specified in section 0 is embedded in a JP2 file. The complete file format syntax for the JP2 file can be found in Annex I of the JPEG2000 standard [JPEG2k]. A JP2 friction ridge production file shall contain the JPEG2000 Signature Box, a File Type Box, a JP2 Header Box and the Codestream Box as shown in Figure 1. Further information on the contents of these boxes can be found in Table 3.

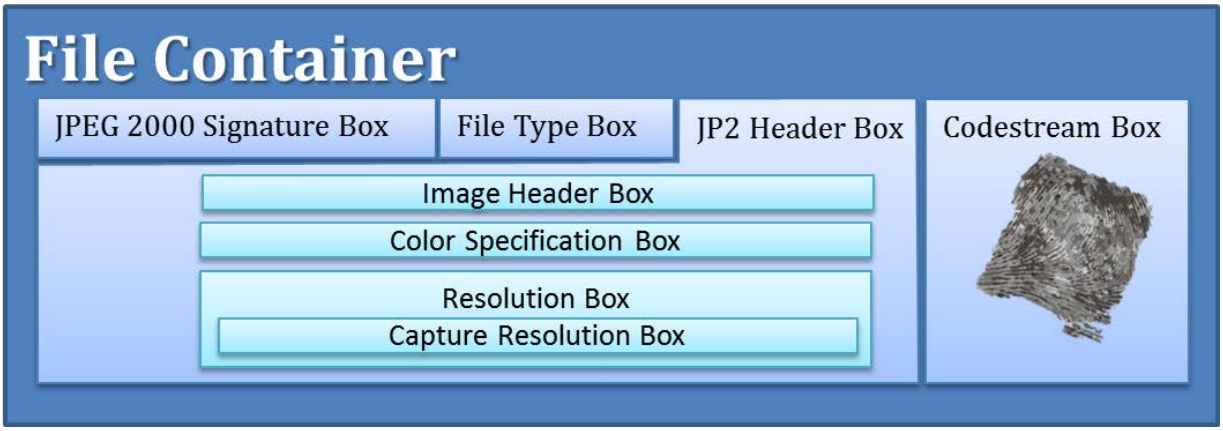

Figure 1 - JPEG2000 Friction Ridge Production File Overview

Table 3 - JPEG2000 Friction Ridge Production File Specifications

JP2 Box / Data Field	Value	Size (Bytes)	Hexadecimal
JPEG2000 Signature Box			
Length	12	4	0000 000c
Type	'jP<SP><SP>'	4	6A50 2020
Signature	'<CR><LF><0x87><LF>'	4	0D0A 870A
File Type Box			
Length	20	4	0000 0014
Type	'ftyp'	4	6674 7970
Brand (BR)	'jp2<SP>'	4	6A70 3220
Minor Version (MinV)	0	4	0000 0000
Compatibility List (CL)	'jp2<SP>'	4	6A70 3220
JP2 Header Box (Superbox)			
Image Header Box			
Length	22	4	0000 0016
Type	'ihdr'	4	6968 6472
Height	Image Area Height (pixels)	4	
Width	Image Area Width (pixels)	4	
Number of Components (NC)	1	2	0001
Bit Depth minus 1 (BPC)	7 (Corresponds to 8bpp)	1	07
Compression Type (C)	7 (JPEG2000)	1	07
Colorspace Unknown (UnkC)	0	1	00
Intellectual Property (IPR)	0	1	00
Color Specification Box			
Length	15	4	0000 000F
Type	'colr'	4	636F 6C72
Method (METH)	1 (Enumerated Colorspace)	1	01
Precedence (PREC)	0 (reserved)	1	00
Approximation (APPROX)	0 (reserved)	1	00
Enumerated Colorspace (EnumCS)	17 (grayscale)	4	0000 0011
Resolution Box (Superbox)			
Length	26	4	0000 001A
Type	'res '		7265 7320
Capture Resolution Box			
Length	18	4	0000 0012
Type	'resc'	4	7265 7363
Vertical Capture Resolution Numerator (VRcN)	39 370[8]	2	99CA
Vertical Capture Resolution Denominator (VRcD)	1	2	0001
Horizontal Capture Resolution Numerator (HRcN)	39 370[8]	2	99CA
Horizontal Capture Resolution Denominator (HRcD)	1	2	0001
Vertical Capture Resolution Exponent (VRdE)	0	1	00
Horizontal Capture Resolution Exponent (HRdE)	0	1	00
Identification and MetaData (Comment) Box			
Marker Code	COM	2	0xFF64
Comment Length (Lcom)	104	2	0x0068
Registration Value (Rcom)	1 (ISO/IEC 8859-15 data)	2	0001
Comment Contents	see section 4.3	100	
Contiguous Codestream Box	See section 0		

[8] Values for VRcN and HRcN are specified here in pixels per millimeter according to [JPEG2K]. A value of 39 370 corresponds to 1000 pixels per inch.

4.3. Identification and Metadata (Comment) Box

The Identification and Metadata Box is a special purpose comment box that can accommodate up to 100 bytes of structured ISO/IEC 8859-15 [ISO/IEC99] data. This data, also referred to as "comment contents", is used for certification and identification. The structure of the data is described in Table 4 and a sample of this data is provided in Table 5 below.

Table 4 - Identification and Metadata Structure

Data Segment Description	Start Position	Length	Contents
Encoder Identification Tag	0	6	'EncID:'
Encoder Identification Data	7	20	Determined by receiving entity requirements.
Reserved Block Tag	28	6	Reserved for future use.
Reserved Block Data	35	65	Reserved for future use.

Table 5 - Sample Contents for the Identification and Metadata Box

Guide	0123456789012345678901234567890123456789012345678901234567890123456789012345678901234
Contents	'EncID: NIST-000000000000001 Resvd: e3b0c44298fc1c149afbf4c8996fa92427ee41e5649b934cb495991b7852b855 '

The information requirements for the Identification and Metadata box are dictated by the receiving entity's guidance and certification/non-repudiation requirements.

4.4. Interoperability with Traditional 500 ppi Systems

NISTIR-7839 [NISTIR7839] examined several methods and identified a strategy utilizing Gaussian low-pass filtering ($\sigma = 0.8475$ and $r = 4$) combined with decimation downsampling to provide a pathway to downsample images from 1000 ppi to 500 ppi for use in traditional processing pathways. Following the downsampling process, the resulting 500 ppi imagery shall be compressed using the guidance in [AN2k11] for compression of 500 ppi imagery. While this approach may not be optimal in throughput performance, it provides for a means of downsampling from 1000 ppi that can operate on any 1000 ppi grayscale imagery regardless of perquisite JPEG2000 compression stream specific requirements. Sample source code and further information on this strategy can be found in NISTIR-7839.

In assessing the many possible downsampling approaches, it is most notable that the human examiners were able to detect statistically significant differences in image quality among the various alternatives. Thus, in spite of theoretical expectations regarding the capability of downsampling via other means, including extraction of 500 ppi images directly from the 1000 ppi JPEG2000 codestream, empirical evidence weighs in favor of the Gaussian filtering approach described in NISTIR 7839. Other schemes may be justified for throughput, convenience, or other considerations, but at the cost of image quality.

5. Supporting Basis

This section provides the supporting basis for the selection of the various parameters provided in this guidance.

5.1. Base Raster Format

The base raster format for 1000 ppi friction ridge imagery has been specified as an 8-bit gray scale image without an alpha channel. The image can be constructed using an indexed grayscale color space. Grayscale image shall consist of pixels, each of which shall be quantized to eight bits (256 gray levels) and held in a single unsigned byte where a value of zero shall represent a true black pixel and a true white pixel shall have a byte value of 255.

5.2. Expected Image Geometry

This guidance is based on a fixed final compression ratio specification (relative to the original image size without employing compression) as opposed to specifying a target compression bitrate, which is how the WSQ algorithm is applied when compressing 500 ppi fingerprint imagery. This strategy provides for more predictable outcomes in terms of system sizing, but the bandwidth available to fingerprint friction ridge detail can vary by the overall image geometry.

This section provides the basis for the various image geometries that the guidance applies to.

5.2.1. Single Rolled or Flat, Card Scan or Live Capture

The ANSI/NIST [AN2k11] and EBTS [CJIS] standards define the following single impression geometries:

- A rolled impression at 1.6" x 1.5" in size or approximately 2.4 million pixels at 1000 ppi (EBTS 9.4 [CJIS]).
- A flat (plain) impression up to 1" x 2" in size or approximately 2.0 million pixels at 1000 ppi (EBTS 9.4 [CJIS]).
- ANSI/NIST-ITL 1-2011 [AN2k11] specifies that rolled impression images can be up to 1.6" x 1.5" in size (2.4 million pixels at 1000 ppi).
- ANSI/NIST-ITL 1-2011 specifies that flat (plain) impression images can be up to 1.0" x 3.0" in size (3.0 million pixels at 1000 ppi).
- ANSI/NIST-ITL 1-2011 specifies that Entire Joint Image (EJI) impression images can be up to 4.5" x 5.0" in size (22.5 million pixels at 1000 ppi).
- ANSI/NIST-ITL 1-2011 specifies that unknown friction ridge impression images can be up to 5.5" x 8.0" in size (46.75 million pixels at 1000 ppi).
- PIV specifications calls for single finger capture images to be at least 12.8 mm by 16.5mm high +- 0.02 % (302 400 pixels at 1000 ppi).

Based on the above, the normal operational range for Single Rolled or Flat fingerprint imagery geometry (for both Card Scan and Live Capture) is expected to be from 302 400 pixels to 46 750 000 pixels at 1000 ppi.

5.2.2. Multi-Finger Slap or Palm

The ANSI/NIST [AN2k11] and EBTS [CJIS] standards define the following multi-finger impression geometries:

- EBTS 9.4 specifies image dimensions 5.5" x 8.0" (44 million pixels at 1000 ppi) for a full palm.
- EBTS 9.4 indicates 5.5" x 5.5" (30.25 million pixels at 1000 ppi) for a half palm impression.
- EBTS 9.4 specifies that writer's palm impressions be captured at 1.75" x 5.0" (8.75 million pixels at 1000 ppi).
- EBTS 9.4 preferred dimensions for plain four-finger slap impressions is 3.2" x 3.0" (9.6 million pixels at 1000 ppi).
- ANSI/NIST-ITL 1-2011 specifies image dimensions of 5.5" x 8.5" (46.75 million pixels at 1000 ppi) for a full palm impression image
- ANSI/NIST-ITL 1-2011 specifies image dimensions of 5.5" x 5.5" (30.25 million pixels at 1000 ppi) for half palm impression image

- ANSI/NIST-ITL 1-2011 specifies image dimensions of 1.8" x 5.0" (9 million pixels at 1000 ppi) for writer's palm impression image
- ANSI/NIST-ITL 1-2011 specifies image dimensions of 6.5" x 8.5" (55.25 million pixels at 1000 ppi) for a full palm impression which also includes a writer's palm impression within the same image.
- ANSI/NIST-ITL 1-2011 specifies 1.6" x 1.5" (2.4 million pixels at 1000 ppi) for two-finger plain impressions.
- ANSI/NIST-ITL 1-2011 specifies 5.5" x 3.0" (16.5 pixels at 1000 ppi) for interdigital palm impression images.
- ANSI/NIST-ITL 1-2011 specifies 3.0" x 4.5" (13.5 million pixels at 1000 ppi) for thenar or hypothenar palm impression images.
- ANSI/NIST-ITL 1-2011 specifies 5.5" x 4.5" (24.75 million pixels at 1000 ppi) for carpal delta palm impression images.
- ANSI/NIST-ITL 1-2011 specifies 1.6" x 1.5" (2.4 million pixels at 1000 ppi) for a two-finger plain impression image.
- ANSI/NIST-ITL 1-2011 specifies 2.5" x 1.5" (3.75 million pixels at 1000 ppi) for a three-finger plain impression image.
- ANSI/NIST-ITL 1-2011 specifies 3.2" x 3.0" (9.6 million pixels at 1000 ppi) for a four- and five-finger plain impression image or an image containing two plain thumb impressions.

Based on the above, the normal supported operational range for multi-finger slap or palm impressions (for both Card Scan and Live Capture) is expected to be from 2 400 000 pixels to 55 250 000 pixels at 1000 ppi.

5.2.3. Latent

Currently there are no established minimum or maximum sizes defined for latent imagery. As a placeholder, the maximum size of the compressed latent is defined here as the maximum dimensions of a paper collection card of 8" x 8" (64 000 000 pixels at 1000 ppi).

5.2.4. Mobile ID Single or Multi Finger Flat or Rolled

NIST SP500-280 [MOBID] recommends various image dimensions for fingerprint impression capture conformant with each of a series of Subject Acquisition Profiles (SAP)/Fingerprint Acquisition Profiles (FAP). The Mobile ID best practices recommendation gives ranges for single print plain impressions of 0.5" x 0.65" (325 000 pixels at 1000 ppi) to 0.8" x 1.0" for SAP 10 to 30; one or two prints 1.6" x 1.5" for SAP 30 and 40 either plain or rolled; one to three prints 2.5" x 1.5" for SAP 50; and one to four prints 3.2" x 3" (9 600 000 pixels at 1000 ppi) for SAP 60.
Thus, for the recommended operational range for mobile ID single and multiple fingerprint capture, image sizes range from 325 000 pixels to 9 600 000 pixels at 1000 ppi.

5.2.5. Plantar Impressions

The studies that this guidance has been based on did not include examination of plantar prints. This may be addressed in a later revision of this document. In the interim, it is recommended that the case of plantar prints be compressed with the same compression parameters as multi-finger slap or palm impressions even though the expected geometry of such images will exceed what is expected from multi-finger or palm impressions (see 5.2.2).

5.3. Code block dimensions

In compressing an image using the JPEG2000 algorithm, the components of a given image are divided into rectangular tiles. Each tile is the basic unit of the compression/decompression process. Wavelet transformations are performed on each tile component which results in the decomposition levels. Each decomposition level is composed of sub-bands of coefficients that describe the frequency components that

make up the tile component. The sub-bands of coefficients are partitioned into rectangular code-blocks. To aid in interoperability, Profile-1 (which is a slightly restricted subset of the JPEG2000 syntax) has been selected as the basis for this compression guidance. JPEG2000 Profile-1 allows a code-block size of 64x64 or smaller. Anecdotal evidence suggests that smaller code-block sizes can reduce compression efficiency therefore a code-block size of 64x64 shall be utilized. It should also be noted that NISTIR-7778 utilized images that were compressed with a code-block size of 64x64. For further information on code-stream profiles refer to [JPEG2K].

5.4. Wavelet Decomposition Levels

The tile-components of a given image are decomposed into different decomposition levels using a wavelet transformation. Each of these decomposition levels contains a number of sub-bands containing coefficients that describe horizontal and vertical spatial frequency characteristics of the original tile-component. These coefficients provide frequency information about a local area rather than the entire image and image compression (and thereby a reduction in size) is obtained by describing that area of the image with only a few coefficients. Each decomposition layer in the hierarchy of decomposition layers is related to the next adjacent decomposition level by a spatial factor of two. Therefore, the higher decomposition level has twice the resolution as the next lower one, with the top level being at the full resolution of the original sample. This process can be useful in applications where there is a need to downsample the image resolution by a factor of 1/2 rapidly.

Anecdotal evidence suggests that available JPEG2000 CODECs typically default to 5 or 6 decomposition levels. [MITRE] recommends 6 decomposition layers as default to facilitate interaction with WSQ at 500 ppi. Empirical tests detailed in [NISTIR7939] find either 5 or 6 decomposition levels to be optimum with respect to computational metrics which examine image structural fidelity in comparison to non-compressed source images. While either specification should be appropriate, 6 decomposition levels should provide additional headroom for extraction of lower resolution images from the compressed data. Hence, we recommend compression using 6 wavelet decomposition levels.

NISTIR 7939 examined the potential impact of using different counts of decomposition levels when compressing fingerprint using JPEG2000 with a lossy filter on 1000 ppi fingerprint imagery. To do so, a random sample (100 images) of the image set utilized in [NISTIR-7839] was selected for this study. Each of the 1000 ppi source images was compressed at 10:1 setting the JPEG 2000 CODEC's decomposition level parameter to one of six values ranging from three to eight decomposition levels. Decoded compressed images were then paired with their non-compressed source images for presentation to trained latent fingerprint examiners. The ratings of the examiners showed no statistically significant differences among images compressed at the six decomposition levels specifications.

5.5. Quality Layers

The JPEG2000 standard allows for specification of a series of "quality layers" corresponding to a list of compression ratios retrievable from the code stream upon decoding. For various JPEG2000 CODECs this ordered list of either compression ratios or bit rates includes the target compression level at either the beginning or end of the list. Thus, for the NIST JPEG2000 CODEC (modified from V 1.4 of the OpenJPEG 2000 CODEC, see section 6), one such quality layer specification might be for example {10, 15, 24, 34, 58, 86, 144, 214} in which the target final compression ratio is 10:1, but with decoding options for lower quality (higher compression ratio/lower bit rate) versions of the image ranging from 15:1 to 214:1 in this example.

These higher compression ratio (lower bit rate) images are not lower in sample rate than the original source image, thus decoding the compressed code stream at lower quality does not provide an image of lower dimension. The image decoded from the 214:1 portion of the codestream compressed using the above quality

level specification will include the same number of pixels as the decoded 10:1 image and even the non-compressed source image, but will contain less spatial detail. If selection of lower quality is combined with discard of resolution levels, some savings might be realized in transmission bandwidth requirements for some applications for which maximum resolution and fidelity are not required.

Measured with a suite of computational fidelity metrics [NISTIR7939], small fidelity losses relative to non-compressed source images were observed when using more than a single quality layer. However, such losses were extremely small relative to that of compression at even a single quality layer and were determined to lie well below the visual threshold of trained fingerprint examiners. The present recommendation is to use six quality layers to include compression ratios, x:1, where x = {10, 15, 20, 30, 40, 60, 80}.

5.6. Progression order

For a given tile, the packets in that tile contain data from a specific quality layer, component, resolution level, and a specific precinct (position). The order in which these packets are defined in the compressed codestream for friction ridge imagery in this guidance is Resolution-Position-Component-Layer (RPCL) and has been grandfathered in from [MITRE].

5.7. Number of Components

Friction ridge imagery at 1000 ppi shall be sampled in a grayscale color space, which corresponds to one component being defined in the JPEG2000 stream.

5.8. Filter Type

For fingerprint impression types other than latent imagery, the user shall utilize a 9-7 (Irreversible) lossy filter for compression.

For latent friction ridge imagery, the user shall utilize a 5-3 (Reversible) lossless filter for compression.

5.9. Resolution Box

Since this profile is specifically for the compression of 1000 ppi images, the data in the resolution box must reflect capture at 1000 ppi. The data in the Resolution Box is presented in English units with a value of pixels-per-inch.

5.10. Compression Ratio

In 1992, a study conducted by the International Association for Identification (IAI) [FITZPATRICK] established 15:1 as the target compression ratio for 500 ppi fingerprint imagery using the [WSQ] compression algorithm. Since the WSQ algorithm is specifically designed and tuned for operation on 500 ppi imagery, the results of the IAI study and the subsequent compression guidance for WSQ was limited in application to 500 ppi fingerprint imagery. In 2011, NIST replicated this study with 1000 ppi imagery using the JPEG 2000 compression algorithm in [NISTIR7778]. The IAI study determined that a maximum rate of 3.4 % observed level 3 degradation based on the number of cases examined was acceptable when comparing the lossy-compressed fingerprint to the control case which has never passed through lossy compression. Each treatment case in NISTIR-7778 consisted of 200 image pairs which equates to a limit of 6.8 observed cases of level 3 degradation according to IAI's methodology. Since there can be no fractional observations, this was rounded down to a limit of 6 observed cases of level 3 detail degradation for NISTIR-7778. The results of NISTIR-7778's comparison of rolled, flat and slap imagery for both live scan and card scan can be found in Table 6 and Table 7 respectively. The tables

indicate the number of images assigned by examiners to each of the four degradation categories at each thirteen compression ratios. NISTIR-7778 examined both homogenous impression pairings such as flat-to-flat, as well as heterogeneous pairings such as flat-to-rolled. Since the IAI guidance was based on homogenous pairings of the same impression only, only those cases have been provided in the tables below.

Table 6 - Observed Compression Anomalies for Non-Mixed Cardscan Impressions

Card Scan (Ink)	2:1	5:1	7:1	10:1	12:1	15:1	17:1	20:1	22:1	26:1	30:1	34:1	38:1
Ink Rolled to Ink Rolled, Mated Pair													
Level 2 and 3 detail degradation	0	0	0	0	0	0	0	0	0	1	0	0	3
Level 3 detail degradation	0	4	4	6	10	8	16	11	23	28	29	32	36
Some benign degradation	34	45	67	92	107	112	125	133	131	126	133	141	134
No visible degradation	166	151	129	102	83	80	59	56	46	45	38	27	27
Ink Flat to Ink Flat, Mated Pair													
Level 2 and 3 detail degradation	4	0	0	0	0	3	1	0	1	3	3	4	5
Level 3 detail degradation	2	3	3	2	10	6	9	11	18	20	18	35	47
Some benign degradation	19	20	47	68	79	98	107	112	118	118	119	109	104
No visible degradation	175	177	150	130	111	93	83	77	63	59	60	52	44
Ink Slap to Ink Slap, Mated Pair													
Level 2 and 3 detail degradation	1	1	0	1	0	0	1	0	1	1	2	0	1
Level 3 detail degradation	0	1	4	1	9	11	11	8	8	14	14	18	24
Some benign degradation	20	20	26	37	51	67	80	101	103	117	116	117	115
No visible degradation	179	178	170	161	140	122	108	91	88	68	68	65	60

Table 7 - Observed Compression Anomalies for Non-Mixed Livescan Impressions

Live Scan	2:1	5:1	7:1	10:1	12:1	15:1	17:1	20:1	22:1	26:1	30:1	34:1	38:1
Livescan Rolled to Livescan Rolled, Mated Pair													
Level 2 and 3 detail degradation	0	0	1	0	2	1	1	1	1	1	0	1	1
Level 3 detail degradation	1	1	0	2	4	2	12	13	33	45	62	63	69
Some benign degradation	36	43	58	75	109	124	139	146	136	131	119	117	113
No visible degradation	163	156	141	123	85	73	48	40	30	23	19	19	17
Livescan Flat to Livescan Flat, Mated Pair													
Level 2 and 3 detail degradation	0	1	1	1	1	0	1	0	1	0	1	1	0
Level 3 detail degradation	0	0	1	0	2	0	1	3	3	6	6	8	13
Some benign degradation	31	30	31	42	37	55	64	68	56	75	73	77	63
No visible degradation	169	169	167	157	160	145	134	129	140	119	120	114	124
Livescan Slap to Livescan Slap, Mated Pair													
Level 2 and 3 detail degradation	0	0	0	0	0	0	0	0	0	0	0	0	0
Level 3 detail degradation	0	0	0	0	0	1	2	1	3	1	3	9	11
Some benign degradation	5	6	12	30	50	81	103	125	129	141	143	146	149
No visible degradation	195	194	188	170	150	118	95	74	68	58	54	45	40

Given the experimental data, the highest compression rate where all cases of observed level 3 detail degradation number 3.4 % or less for all impression types is 10:1 for card scan imagery and 15:1 for live scan imagery.

While an optimal solution for compression rate would be to select 10:1 for card scan imagery and 15:1 for live scan imagery, experimental results show mixed compression rates can negatively impact the matcher where for example a 10:1 card scan image were to be compared to a 15:1 live scan image in the gallery. In this experiment a set of 2448 card-scan fingerprint images were compressed at 2:1, 5:1, 7:1, 10:1, 12:1, 15:1 and 17:1. The fingerprint images were matched against themselves (same impression, same image) at several different

combinations of compression ratios as shown in Figure 2. The images of different identities were also matched against each other as 496 944 non-mate cases using the same compression ratio combinations. For the specific mixed compression scenario of 10:1-to-15:1, the median score obtained from matching mated images was 224 while the same images in the 10:1-to-10:1 scenario yielded a median match score of 499. These results were determined to be statistically significant using Wilcoxon signed rank test (P<0.0001).

NISTIR-7778 had a focused scope in that it only examined the impact of compression as it relates to exemplar fingerprint images (fingerprint images that have been captured under controlled conditions). NISTIR-7780 on the other hand focused on the impact of lossy compression in scenarios that are typically involved in latent casework (friction ridge imagery that typically has been captured as evidence at the scene of a crime under uncontrolled conditions).

There are two key scenarios in NISTIR-7780 that best represent the bulk of typical operational latent casework. These two scenarios include the comparison of a lossless latent fingerprint to a lossy compressed rolled exemplar, and the comparison of a lossless latent to a compressed flat exemplar fingerprint to establish identity in both cases.

For these two scenarios of interest, the ideal condition (as defined through anecdotal evidence) is comparing a lossless latent image to a lossless exemplar image where neither image has undergone any lossy compression. NISTIR-7780 showed that the largest contiguous range of lossy compression applied to Rolled and Flat exemplar fingerprint images that yields performance indistinguishable from the ideal case (1:1 exemplar to 1:1 latent) ranges from 2:1 to 12:1.

Exploratory testing of automated matcher behavior[9] using lossy compressed images for this special publication showed a tendency by the automated matcher to favor like-vs.-like cases in terms of compression ratio (see Figure 2) and there was a slight penalty where the compression ratio of the probe differed from that of the gallery.

In summary, the data in this section shows an optimal compression rate of is 10:1 for card scan imagery, 15:1 for live scan imagery, and 12:1 for exemplars meant to be compared to latent imagery. Based on the automated matcher behavior data however, the compression rate of 10:1 shall be applied to all exemplar impressions to mitigate any potential performance degradation resulting from mixed compression cases (i.e., 10:1 to 15:1).

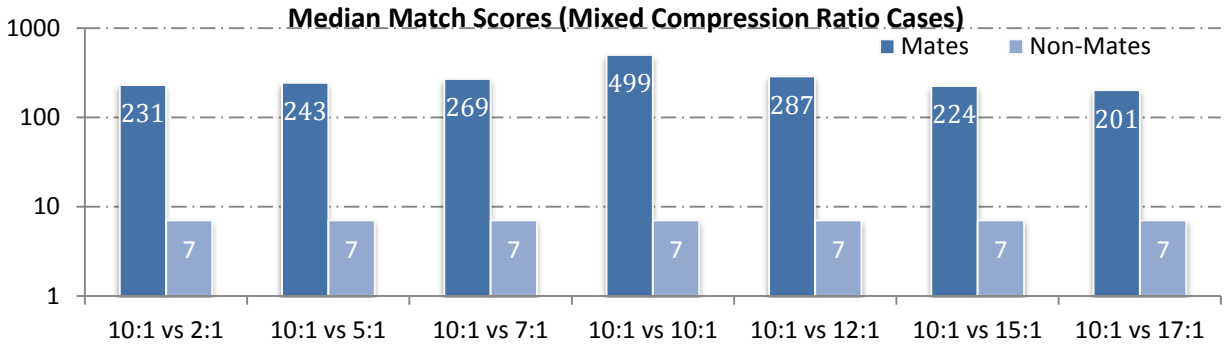

Figure 2 - Mixed Compression Ratio Cases

[9] Matcher testing of mixed compression pairs was conducted using the BOZORTH3 NIST research matcher, using the SD27A 1000 ppi data set. The test consisted of matching 2448 mated pairs, and 496 945 non-mated pairs at the noted mixed compression cases to generate match scores.

5.11. Interoperability Guidance

With the transition to 1000 ppi, some systems will unavoidably contain an overlap between traditional 500 ppi and 1000 ppi operational pathways. To create a bridge between traditional and modern data there needs to be a pathway for interoperability putting traditional and modern data on equal footing by converting one of the images to the same resolution as the other. Downsampling of the higher resolution 1000 ppi imagery to 500 ppi provides this pathway.

Several different analysis methodologies/algorithms were used in NISTIR-7839 to identify an optimal strategy. These methods included various different fidelity measures (such as expert examiners or machine matcher score assessment) for each treatment as well as several different methods of fusing the results of these measures such as clustering ranks.

Based on the findings in NISTIR-7839, the Gaussian treatment (σ = 0.8475, r = 4, with odd-column/odd-row decimation) is identified as the top performing downsampling strategy using the measures of Ordinal Rank Summation, Mean Rank Summation and Expert Examiner Winner-Take-All. Where Gaussian treatment (σ = 0.8475, r = 4) is not identified as the best performer, it is identified as next best (or tied as such) excluding the control case.

Table 8 below shows the ranking of Gaussian treatment (σ = 0.8475, r = 4, with odd-column/odd-row decimation) within each of the analysis methodologies. Following the downsampling process, the resulting 500 ppi imagery shall be compressed using the guidance in [AN2k11] for compression of 500 ppi imagery.

Table 8 - Summary of Findings

Measure Fusion Method	Ranking of Gaussian (σ = 0.8475)	Notes
Clustered Rank Summation (Optimistic Decimation)	1	Statistically clustered at rank-1 with Gaussian σ = 0.6773, 0.7624 , 0.5922, 0.8475 , 0.5642, 0.9326, 0.5071, 1.0177, 0.4220, 0.3369
Clustered Rank Summation (Conservative Decimation)	1	Statistically clustered at rank-1 with Gaussian σ = 0.9326, 0.8475, 0.6773, and Spectral Truncation
Ordinal Rank Summation (Optimistic Decimation)	1	
Ordinal Rank Summation (Conservative Decimation)	2	Gaussian σ = 0.9326 is at rank-1
Mean Rank Summation (Optimistic Decimation)	1	
Mean Rank Summation(Conservative Decimation)	2	Gaussian σ = 0.7624 is at rank-1
Expert Examiner Winner-Take-All	1	

6. Tools

A NIST modified version of the OpenJPEG 2000[10] reference JPEG2000 CODEC is available on the NIST NBIS site at `http://fingerprint.nist.gov/NFIS/`

The modifications made to this reference CODEC allow for a single command line option parameter that enables all recommended encoder settings provided in this guidance. For further information please refer to the documentation provided with NBIS.

[10] Available at `http://www.openjpeg.org/`

7. Glossary and List of JPEG2000 Acronyms

The abbreviations and acronyms found in Table 9 refer to terminology found in the JPEG 2000 standard [JPEG2k]. A basic definition of each term is provided below; however for a more detailed explanation of each value please refer to [JPEG2k] sections A.5.1, A.6.1, A.6.2, and A.15.

Table 9 - List of JPEG2000 Codestream Acronyms

Csiz	The number of components in the image
Rsiz	Denotes the capabilities that a decoder needs to properly decode the codestream
Ssiz	The precision (depth) in bits and sign of a given component
Xsiz	The width of the reference grid
XRsiz	Horizontal separation of a sample with respect to the reference grid
XTSiz	Width of one reference tile with respect to the reference grid
XTOSiz	Horizontal offset from the origin of the reference grid to the left side of the first tile
Ysiz	Height of the reference grid
YRsiz	Vertical separation of a sample with respect to the reference grid
YTSiz	Height of one reference tile with respect to the reference grid
YTOSiz	Vertical offset from the origin of the reference grid to the left side of the first tile
xcb	Code-block width exponent offset value
ycb	Code-block height exponent offset value
SPcod	Parameters for coding style designated in Scod (Coding style for all components)
SPcoc	Parameters for coding style designated in Scoc (Coding style for this component)

8. References

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9. Standards

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