NIST Special Publication 500-306

Certification Pathway for Downsampling 1000 ppi Fingerprint Friction Ridge Imagery to 500 ppi

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U.S. Department of Commerce
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VERSION HISTORY

Date	Activity

Disclaimer

Specific hardware and software products identified in this report were used in order to perform the evaluations described in this document. In no case does such identification of any commercial product, trade name, or vender, imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products and equipment identified are necessarily the best available for the purpose

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TERMS AND DEFINITIONS

Table 1 – Abbreviations

CJIS	Criminal Justice Information Services Division
CODEC	Encoder and Decoder
FBI	Federal Bureau of Investigation
IAI	International Association for Identification
ITL	Information Technology Laboratory
JPEG	Joint Photographic Experts Group – ISO/IEC committee developing standards for image compression
NBIS	NIST Biometric Image Software
NIST	National Institute of Standards and Technology
PGM	Portable Graymap (image) Format
ppi	Pixels per inch
ppmm	Pixels per millimeter
SIVV	Spectral Image Validation/Verification Metric
WSQ	Wavelet Scalar Quantization – algorithm for compression of fingerprint imagery

ABSTRACT

The document describes the procedure by which fingerprint image downsampling procedures will be evaluated with respect to conformance to the NIST guidance for sample rate reduction of 1000 ppi[1] friction ridge images to 500 ppi as specified in NIST Special Publication 500-289 [NIST3]. This guidance is to be followed whenever 1000 ppi images are to be prepared for comparison to legacy 500 ppi fingerprint databases for submittal to the FBI's Next Generation identification system and conformance will ensure that CODECs produce encoded files that retain fidelity to the non-compressed source images within empirically set limits and that such files can be decoded by other conformant JPEG 2000 CODECs maintaining the required fidelity. The document describes the attributes of a set of fingerprint images selected for conformance testing and the rationale for selection of these images based on spatial frequency fidelity of downsampled images to non-compressed images scanned at 500 ppi where downsampling is performed using the Gaussian filter with subsampling method specified in NIST SP 500-289. The document describes the procedure to be followed in having an algorithm tested for conformance, the metrics used to measure conformance, and provides instructions on how to run the protocol and submit results to NIST for evaluation.

KEYWORDS

Fingerprint lossy compression; Gaussian filter; downsampling; transcoding; 500 ppi fingerprint imagery; 1000 ppi fingerprint imagery; JPEG 2000;

[1] ppi = pixel per inch; 1000 ppi equals 39.4 pixels per millimeter (ppmm). Resolution values for fingerprint imagery are specified in ppi throughout this document. This is based on widely used specification guidelines for such imagery and is accepted as common nomenclature within the industry. Herein SI units are only presented once.

1. Background

The criminal justice community has traditionally exchanged and stored fingerprint imagery data at 500 ppi, yet modern biometric systems are trending towards the transfer and storage of images at 1000 ppi. Transitioning to 1000 ppi images offers many benefits, notably greater fidelity to the original sample and better representation of Level 3 features [JAIN]. Both are favorable since they may increase probability of establishing a match/non-match by expert examiners or automated fingerprint matchers.

However, the transition to 1000 ppi systems will also unavoidably contain an overlap between 500 ppi and 1000 ppi operational pathways. 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 legacy 500 ppi images, for both one-to-one and one-to-many scenarios.

There are two possible methods of interoperability between 500 ppi and 1000 ppi. The first method involves the downsampling (also known as subsampling) of 1000 ppi images to create a smaller 500 ppi image, while the second method would take a 500 ppi image and upsample it to 1000 ppi. The process of downsampling involves discarding data while upsampling would lead to the introduction of new data. Discarding data is more generally accepted for biometric data processing rather than the introduction of new data (through upsampling).

In 2013, the National Institute of Standards and Technology (NIST) in partnership with the Federal Bureau of Investigation (FBI) concluded an investigation to develop this guidance. NIST conducted a series of methodical studies based on the framework established by the IAI's approach to WSQ [NIST2]. The NIST investigation resulted in a set of specifications to be used as a normative guidance for the compression of 1000 ppi friction ridge imagery. These specifications were published in NIST Special Publication 500-289 [NIST3], and this guidance was adopted by the FBI's Advisory Policy Board (APB) in June 2014.

While SP 500-289 provides guidance on the parameters used with JPEG 2000 to compress 1000 ppi fingerprints, it does not address testing for conformance. NIST Special Publication 500–300 describes a conformance testing methodology to validate JPEG 2000 encoders and decoders (CODECs) to ensure they meet the operational characteristics resulting from the application of parameters defined in NIST SP 500-289 as applied to 1000 ppi friction ridge imagery [NIST4]. This includes compression on both lossy 10:1 and lossless modes. SP 500-289 also sets guidance on downsampling 1000 ppi friction ridge imagery to 500 ppi, which is not covered in SP 500-300. The current document details conformance tests of downsampling methodologies.

Section 2 describes the key resources supporting this effort; Section 3 describes the preparation of a suite of test images, the selection of a suitable subset, and defines the testing metric used to evaluate image fidelity and conformance with downsampling guidance; Section 4 describes testing report cards and the criteria to receive certification (from the FBI); and Section 5 documents procedures for participating in this testing.

2. Key Resources

2.1. Reference Fingerprint Image Set

A carefully selected set of 1000 ppi friction ridge imagery is needed to test implementations of SP 500-289. In NIST SP500-300, we are interested in evaluating JPEG 2000 CODECs for conformance with the format and performance dictates of the guidance. Here, we direct our attention to the application of the downsampling recommendations included in the guidance by measuring the fidelity of downsampled images to images of the same fingerprint impressions sampled at 500 ppi. To this end, a subset of 2 040 fingerprint images was selected from NIST Special Database 27A (SD27A) [SD27].

In this regard, we note that we used for this a version of this database in which each fingerprint card of the original set was re-digitized using an FBI-certified flatbed scanner at each of the three sample-rates, 500 ppi, 1000 ppi, and 2000 ppi. The three scans were performed in close succession without disturbing the placement of the card on the bed of the scanner or lifting the pressure cover of the scanner. Preliminary (not yet documented) experiments of scan repeatability found some variation in gray level composition of images over repeated scans. Such gray level variability was found sufficient to result

in variation in the dimensions and sample regions covered by corresponding fingerprint impressions across the three sample rates. Thus, to ensure direct correspondence between fingerprint regions of interest at all three sample rates, the corner coordinates recorded by the automatic fingerprint image segmentation tool for 500 ppi fingerprint cards were rescaled to re-segment 1000 ppi and 2000 ppi card images so as to sample identical regions of the cards, albeit at different sample rates.

2.2. Reference and Supplier's Downsampling Code

The goal of this testing is to determine whether a supplier's downsampling method conforms to that specified in the NIST SP 500-289 guidance. This not only requires a reference set of fingerprint images, but also a "reference" downsampler to which results from code under evaluation can be compared. In this document, the organization requesting conformance testing is referred to as the "supplier" and the algorithm they desire to be evaluated is referred to as the "supplier's code". Note that it is not the supplier's software implementation of a downsampling method that is shared with NIST, but rather it is the images or compressed files processed by the supplier's downsampler and optionally compression CODECs that are submitted.

The code NIST developed to test the guidance in SP 500-289 is used as the reference downsampler in evaluating code submitted by suppliers. This code, referred to as the **NIST Downsampler**, has been released to the public (at no charge) as part of the NIST Biometric Image Software (NBIS) software distribution [NIST1]. The reference set of fingerprint images used in this test, in order to evaluate suppliers' downsamplers, was generated using the **NIST Downsampler**.

3. Testing Procedure

3.1. Test Image Preparation

The guidance for compression of 1000 ppi fingerprint images, NIST SP500-289 [NIST3] provides a recommendation for downsampling the 1000 ppi image to 500 ppi. Based on extensive evaluations reported in [NIST5], we recommend the 1000 ppi image (either source or that decoded from the JPEG 2000 code stream) be first filtered with a Gaussian having a standard deviation of 0.8475, and a filter radius of 4 pixels and then subsampled by discarding either odd numbered or even numbered rows and columns. In [NIST5] we assume an operational scenario in which a 1000 ppi image will be acquired, compressed using a JPEG 2000 encoder, and then either resampled and encoded directly to a 500 ppi WSQ[2] codestream or decoded from JPEG 2000 and resampled to 500 ppi before undergoing any other lossy encoding. In this context NIST examined five basic approaches to downsampling with variations to total twenty-nine potential downsampling profiles/strategies. Exhibiting the best overall performance, the Gaussian low-pass filter with subsampling as described above, was specified in [NIST3] as the method to be used for downsampling 1000 ppi images to 500 ppi.

The procedure described here pertains only to downsampling. We assume that either the downsampler will be used independent of first-stage compression at 1000 ppi or will operate on decoded 1000 ppi images that have undergone first stage compression using the JPEG2000 algorithm in preparation for recompression using a different CODEC. Procedures relating to this distinction will be covered later, but for the present we describe the preparation of the image test suite.

[NIST3] specifies the downsampling method for reducing 1000 ppi fingerprint images to 500 ppi. For conformance testing we wish to select a small number of images that when downsampled according to the method specified shows a minimum $RMSD_{SIVV}$ (see Section 0) when filtering the 1000 ppi image with a Gaussian having a sigma value of 0.8475, radius of 4 pixels. Moreover, we looked for rather steeply sloping increases in $RMSD_{SIVV}$ toward the left and right of the specified Gaussian.

Each of the 2 040 rolled fingerprint images of the SD27A dataset sampled at 1000 ppi was downsampled using each of eleven Gaussian filters shown in Table 2. The NIST SIVV metric was applied to the downsampled 500 ppi image and to the corresponding non-compressed identical impression sampled at 500 ppi from the fingerprint card and identically segmented.

[2] Wavelet Scalar Quantization – the compression algorithm specified by the FBI for compression, transmittal, and storage of 500 ppi fingerprint images.

Table 2 – Gaussian Filter Parameters

Number	Sigma (σ)	Radius (ρ, pixels)
1	0.5071	3
2	0.5641	3
3	0.5922	3
4	0.6773	3
5	0.7624	3
6	0.8475	4
7	0.9326	4
8	1.0177	4
9	1.1028	4
10	1.1879	5
11	1.273	5

Note that according to the Guidance, the Gaussian filter was applied so as to function as a low-pass "anti-aliasing" filter to reduce the expression of frequency components that should not be present in the image sampled at the lower rate of 500 ppi. The subsampling is done by discarding even (or odd) numbered rows and columns of the filtered 1000 ppi image.

3.2. Test Image Selection

Spectral Image Root Mean Squared Difference

Developed initially as a method to screen fingerprint databases for non-fingerprint images, segmentation errors, or mislabeled sample rates, the Spectral Image Validation Verification (SIVV) metric [LIBERT] provides a comparatively straightforward method by which to assess the frequency structure of an image. Pairwise display of the SIVV signals of source and processed images enables summary visualization of the effects of the process or different processes across the composition frequency spectrum of the image as shown in Figure 1. Here we see the combined effects of lossy compression and downsampling as specified in the guidance. This appears as a slightly lower power over the middle range of frequencies with more substantial drop-off at high frequency when compared to the non-compressed, 500 ppi scan of the same fingerprint impression. That much of this loss of power in the high frequencies is due to the combined effects of the JPEG 2000 compression and the WSQ compression is evident by examination of Figure 2 in which we have the same 1000 ppi image downsampled and compared to its 500 ppi mate with no compression applied at any stage of the process. The SIVV metric comparison in this case exhibits only the effect of the downsampling.

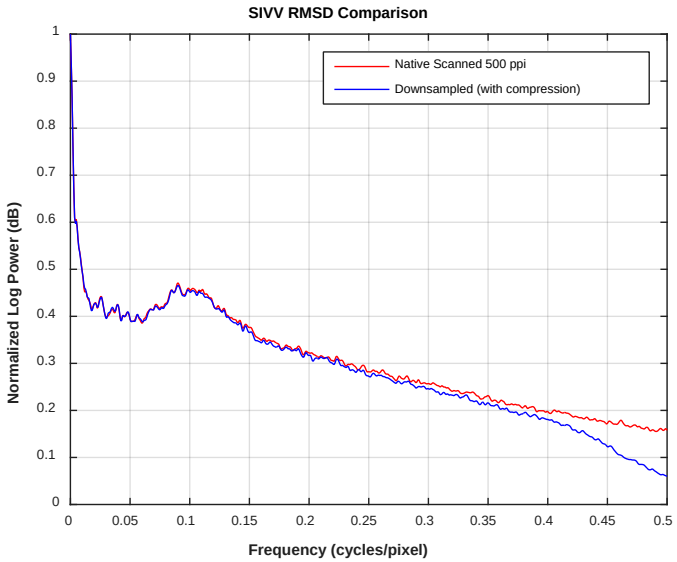

Figure 1 – SIVV signal of a 1000 ppi fingerprint image subjected to both JPEG 2000 and WSQ lossy compression with intermediate downsampling to 500 ppi. Here downsampled image is compared with the SIVV signal of its corresponding version natively scanned at 500 ppi.

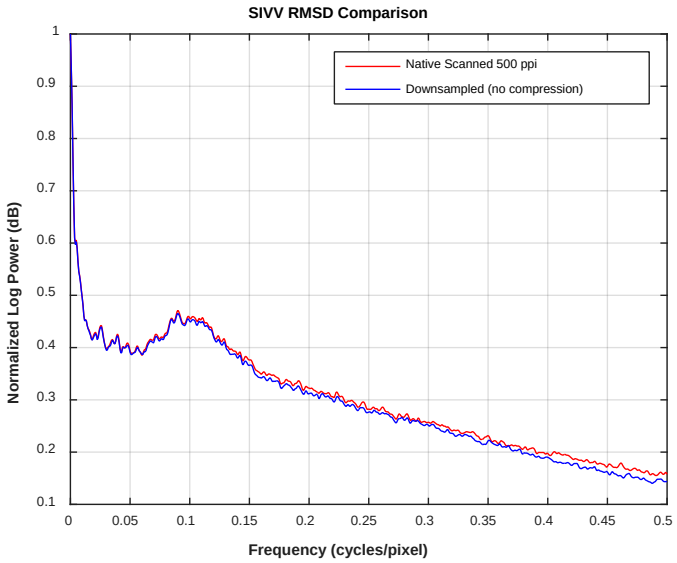

Figure 2 – SIVV signal of a fingerprint image downsampled from 1000 ppi scanned version compared with that of the corresponding fingerprint impression scanned at 500 ppi. No compression was applied to any image in the process.

The metric ($RMSD_{SIVV}$) evaluates the amount of image frequency change in a fingerprint image after it has undergone some process or provides a measure by which to compare the effects of different processes on a fingerprint image. The processed image frequency profile is compared with that of a source or reference fingerprint image.

In the present application, we have a set of 1000 ppi fingerprint images, each of which will be subjected to downsampling, and a corresponding set of images scanned from the same fingerprint cards at 500 ppi and identically segmented such that following downsampling to 500 ppi, the two images should overlay one another almost exactly. For purposes of the

following discussion, we will designate the natively sampled 500 ppi images as P_{SRC} and the downsampled 1000 ppi image as P_{DS}.

Given a source image, $\boldsymbol{I}^{\emptyset}$ (i.e., P_{SRC}), and the subsequently processed image, $\boldsymbol{I}^{\delta}$ (e.g. P_{DS}), corresponding SIVV signal vectors, computed according to [LIBERT] and [NIST1], are denoted $\mathbf{s}^{\emptyset}$ and $\mathbf{s}^{\delta}$. The Root Mean Squared Difference (RMSD) is used to quantify the total amount of image frequency change between the two signals:

$$RMSD_{SIVV} = \sqrt{\frac{\sum_{i=1}^{n}\left(s_i^{\emptyset} - s_i^{\delta}\right)^2}{n}} \tag{6}$$

where $n = |\mathbf{s}^{\emptyset}| = |\mathbf{s}^{\delta}|$ (i.e., the lengths of the signal vectors).

Test Reference Images

The details of test image selection are shown in Appendix B. Essentially the procedure consisted of subjecting each of the SD27A fingerprint images to the eleven Gaussian filter downsampling treatments and computing the SIVV signals of each. As mentioned previously, each of the 1000 ppi images had a corresponding natively scanned 500 ppi version, yielding its own SIVV signal. For each source image, $\boldsymbol{I}^{\emptyset}$, a vector of eleven $RMSD_{SIVV}$ values were computed according to eq. 6.

The the 2 040 vectors of $RMSD_{SIVV}$ values were examined via a custom software tool that selected cases exhibiting a minimum of the selected fidelity metric, the $RMSD_{SIVV}$, for the Gaussian filter method specified in the guidance, NIST SP500-289, and that the values of this metric increase monotonically away from this mimimum for all other Gaussians. Selections were made on this basis exclusive of compression and the procedure was repeated for images subjected to both JPEG 2000 compression prior to downsampling as well as WSQ encoding and decoding following downsampling. This latter procedure was included to ensure that even as the conformance test excluded compression, conformance demonstrated with the test images would persist even with compression.

Table 3 lists the images selected from among the SD27A [SD27] fingerprint database that meet the criterion described above and detailed in Appendix B. The original inked fingerprint cards (FD-249) were scanned at both 1000 ppi and 500 ppi, and these rolled fingerprints were segmented identically from their card images. Thus, though at different sample rates, corresponding fingerprints were as close to identical as possible with respect to area of coverage.

Table 3 – Reference Fingerprint Image Set

Image #	Impression Type	Image W	Image H	Image File Name (from SD27A)
1	Rolled	624	496	003-G003_R08_F14_500_04
2	Rolled	717	626	005-G005_R08_F14_500_06
3	Rolled	663	550	018-G018_R06_F12_500_03
4	Rolled	677	534	026-G026_R09_F14_500_08
5	Rolled	629	509	031-G031_R06_F12-U255_R01_F11_500_06
6	Rolled	487	604	035-G035_R06_F12_500_02
7	Rolled	486	369	039-G039_R04_F13-U286_R06_F12_500_10
8	Rolled	623	500	057-G057_R04_F13_500_02
9	Rolled	608	496	104-B104_R08_F14_500_07
10	Rolled	608	484	107-B107_R09_F14-B108_R06_F12_500_06
11	Rolled	638	531	151-B151_R09_F14_500_08
12	Rolled	472	387	165-B165_R07_F14_500_09
13	Rolled	736	476	176-B176_R07_F14_500_03
14	Rolled	723	587	188-B188_R07_F14-B190_R08_F14_500_02
15	Rolled	739	584	194-B194_R08_F14_500_02
16	Rolled	605	473	202-U202_R08_F14_500_02
17	Rolled	552	454	202-U202_R08_F14_500_05
18	Rolled	483	577	216-U216_R04_F13_500_01
19	Rolled	648	624	222-U222_R03_F13_500_06
20	Rolled	548	661	233-U233_R06_F12_500_01
21	Rolled	685	550	288-U288_R06_F12_500_09
22	Rolled	499	599	298-U298_R02_F13_500_06

Table 8 (See Appendix B) shows for each of the selected test images the vector of $RMSD_{SIVV}$ values by downsampling a non-compressed 1000 ppi image using each of the eleven Gaussian filters and comparing the SIVV signal of each result with that of its corresponding 500 ppi version. The means and standard deviations are shown in the last two rows of Table 8. The means are plotted in Figure 5. Based on the distributions of $RMSD_{SIVV}$ values about what was previously determined experimentally as the optimum Gaussian filter, we set two levels of threshold for average $RMSD_{SIVV}$ for any downsampler under test. The first threshold, GOLD, is the more conservative of the two, yet still allows a fair degree of performance latitude. The Silver level allows even greater variation in downsampler performance.

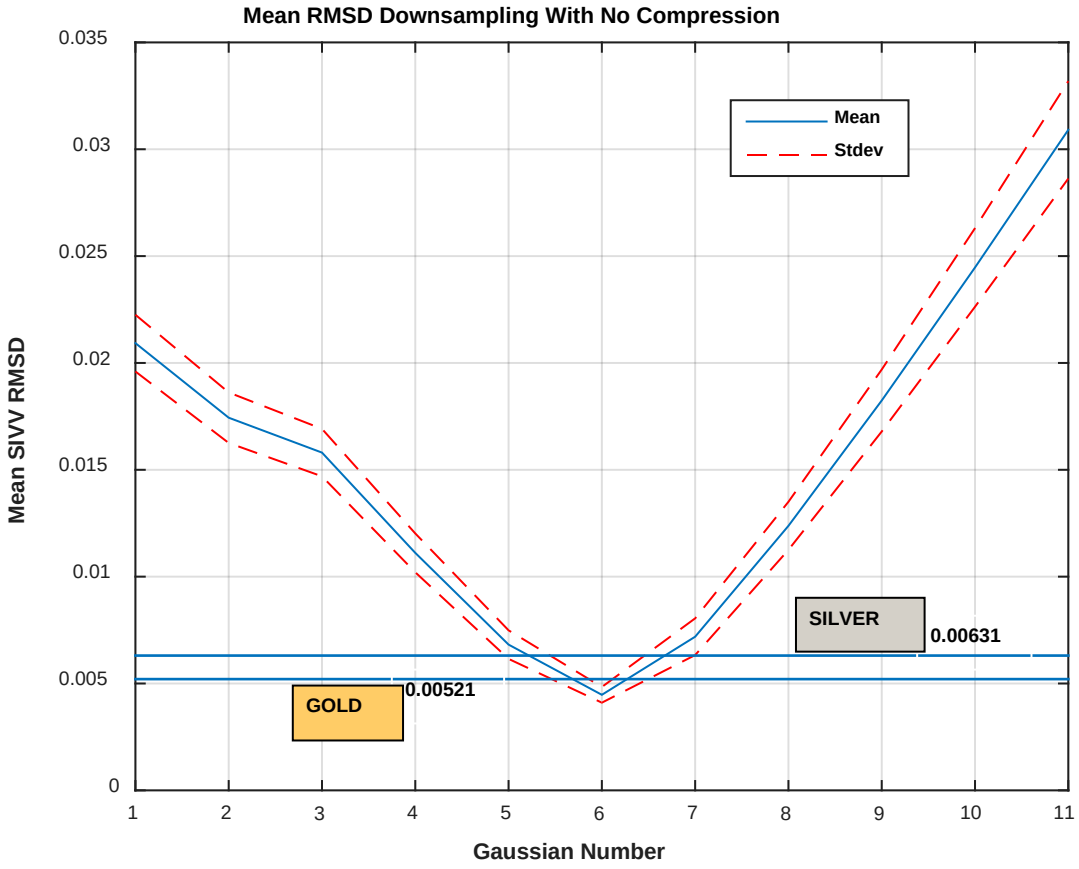

Figure 3 – Mean $RMSD_{SIVV}$ for the selected test images plotted for the eleven Gaussians with standard deviation shown as an error margin. Horizontal lines mark upper limits of downsampling algorithm conformance at three different levels of performance. A "Passing Score" for certification recommendation is issued for a mean $RMSD_{SIVV}$ value < 0.00631, which corresponds to the mean value for the recommended Gaussian downsampling method plus 5 σ.

3.3. Procedure

The data package to be provided by NIST will include twenty-two non-compressed 1000 ppi source images in Portable Graymap Format (PGM) format. Options are described below that will govern the scope of application of the downsampler. In either case, the supplier applies a downsampler to each of twenty-two 1000 ppi test images provided by NIST and returns to NIST a corresponding set of 500 ppi output images, obtained via downsampling the 1000 ppi source images. No compression will be applied at any stage in the process, and the output images returned to NIST will be in the same PGM format as that of the source images.

Downsampler Identification

We anticipate that a downsampler might be used in preparing an image for encoding with the WSQ CODEC [WSQ] or in isolation from WSQ compression. In either case, conformance with the guidance shall be tested by NIST according to the procedures defined herein, with recommendations to the FBI for certification and inclusion on the CPL. In all cases it should be necessary to convey to a recipient of any downsampled image that the downsampling was performed in the approved fashion, i.e., by a certified downsampler. Accordingly, the assigned identifier must be included in the downsampled output.

In the case of stand-alone downsampling, both PGM and PNG are uncompressed image formats which provide for such entries to be made in comment fields, but PGM is recommended as it is more easily implemented and is flexible as to the length of entry, requiring only that the string begin with the "#" sign. PGM is the only format accepted by NIST for the purposes of conformance testing.

In the case of downsampling in preparation for WSQ encoding the identifier will be included in addition to the typically used CODEC identifier in the WSQ code file to indicate that the encoded image has been downsampled prior to encoding using a certified downsampling algorithm.

Downsampler Identifier

Downsampled images encoded in either compressed form (WSQ) or non-compressed form (PGM or PNG) must contain a NIST-assigned downsampler identifier. This identifier must be present in the respective comment field of the file format used to encode the downsampled image, in the form of 100 bytes of structured ISO/IEC 8859-15 [ISO/IEC99] data. The comment field may contain information before and after the 100byte identifier, but the structure of the identifier within the comment field must be composed as described in Table 4. Note that the 100byte identifier below already includes a trailing space in order to allow the identifier to be followed additional information in the comment field. However, it should also be noted that if any information is to precede the identifier, a leading space should be added in front of the identifier in order to avoid any confusion about the identifier and its contents. Table 4 contains only sample data; the actual identification data must be obtained from NIST on a per-implementation basis. See Section 5.1 for information on how to obtain supplier identification data needed for this field.

Table 4 – Identification and Metadata Structure

Data Segment Description	Start Position	Length	Example Contents
Downsampler Identification Tag	0	7	'DsmID: '
Downsampler Identification Data	7	20	'CERT-SUBMISSION-0000'
Reserved Block Tag	27	8	' Resvd: '
Reserved Block Data	35	65	'41ab87823014dcb19113dfcd0902c569265270861a7f2cbdff148a38cc260675 '

3.4. Scoring

SIVV RMSD

The mean of the vendor's $RMSD_{SIVV}$ comparisons will be compared to the thresholds shown in Table 5. For simplicity sake, we will designate the mean $RMSD_{SIVV}$ for the test images at Gaussian number six as μ_6. For the supplier's satisfaction, the rating levels are differentiated as "GOLD" and "SILVER", but either one will suffice to gain a recommendation by NIST for certification by the FBI for addition to the Certified Products List. The more important distinction is whether the downsampler was tested in the context of pre- and post- compression or in full isolation from image compression. This will determine which components must be identified as integrated and hence certified as a unit.

Table 5 – Conformance performance $RMSD_{SIVV}$ score thresholds for certification recommendation.

	Mean $RMSD_{SIVV}$
Gold	$\mu_6 < 0.00521$
Silver	$0.00521 \geq \mu_6 < 0.00631$

Inspection of SIVV Signals

In addition to computation of the $RMSD_{SIVV}$ values as described in Section 3.2, plots of the frequency spectra of unprocessed 500 ppi image and downsampled counterpart will be plotted as shown in Figure 2. These will be inspected for aberrant behavior such as peaks or valleys at unexpected locations or other anomalies that might be missed by averaging of the $RMSD_{SIVV}$ over all images.

Other SIVV tools may be useful here as well, e.g. max peak should be same for both images corresponding roughly to ridge pitch. The evaluation tool built by NIST to examine the returned downsampled images may apply one or more of these comparison metrics to SIVV signals for each of the images in addition to evaluation of the mean $RMSD_{SIVV}$ thresholds shown in Table 5.

4. Conformance Report

The results of conformance tests will be presented in a short report including the determination of "Pass" or "Fail" and the analysis supporting the determination. The primary consideration will be the mean $RMSD_{SIVV}$ thresholds shown in Table 5. However, other analyses of individual images will be weighted according to their severity that will have to be assessed as they are detected.[3]

[3] At present, we can predict neither the likelihood or occurrence nor the severity of anomalies that might be introduced by unknown downsamplers. As conformance testing proceeds, it should be possible to refine the selection of metrics and further mechanize scoring procedures.

5. Procedures for Conformance Testing

Those suppliers wishing to submit SP500-289 implementations of downsampler code for conformance testing to NIST must follow the procedures outlined in this section. This includes obtaining a NIST assigned software identifier (Section 5.1), downloading the NIST reference fingerprint image set (Section 5.25.1); running the NIST images through the supplier's downsampler and storing the resulting images; submitting the supplier's images to NIST for evaluation (Section 5.3).

5.1. Obtaining a NIST Assigned Downsampler Identifier

Prior to processing the conformance test images, the supplier must obtain a NIST assigned software identifier. This identifier must be present in all images processed by the supplier's downsampling code and must be present in conformance test images submitted to NIST for evaluation.

Requests for a software identifier must be sent to fingerprintcompression@nist.gov and the request must contain the following information in the subject and body of the message:

Message Subject should be:

Fingerprint image downsampler identification request

In the message body please include:

Company point of contact name(s)
Company name
Company physical address

Company general phone number
Company point of contact phone number(s), if different than above

Company web site address

Email address to send assigned encoder identifier to.

Request urgency (either normal, or urgent)

CODEC target platform operating system (i.e., VendorX Linux)
Target platform operating system version and service-pack/build level
Target platform architecture (8 bit, 32 bit, 64 bit, x86, etc.)
Compiler used, including version and operating system at time of compilation

Identification number of previously certified WSQ CODEC (if applicable)

In 7 to 10 days typically, you will electronically receive the NIST assigned downsampler identifier.

This identifier must be present in all images processed by the supplier's downsampling code, whether in the form of a compressed WSQ file or a non-compressed PGM or PNG file.

Additionally, the electronic response you will receive from NIST will include a download link for the reference fingerprint image set needed by the supplier for testing.

5.2. Downloading NIST Reference Fingerprint Image Set

The supplier must download the NIST Reference Fingerprint Image Set from NIST. A link to download the NIST Reference Fingerprint Image Set will be provided by NIST in response to the request for NIST assigned vendor identifier (see 5.1).

The reference fingerprint data set will be archived within a portable ZIP format[4] container and organized as shown in Figure 4. The NIST-provided reference images are stored under the `NIST` subdirectory. Inside are the twenty-two source image files (P_{SRC}) stored in PGM format. The basenames of these files are what is listed in the fifth column of Table 3, which are appended with a tag and file extension, "`-SRC.pgm`". Initially, the `Supplier` subdirectory is empty. The processed images generated by the supplier's downsampling code will be stored in this folder and the entire package zipped back up and then submitted back to NIST for evaluation.

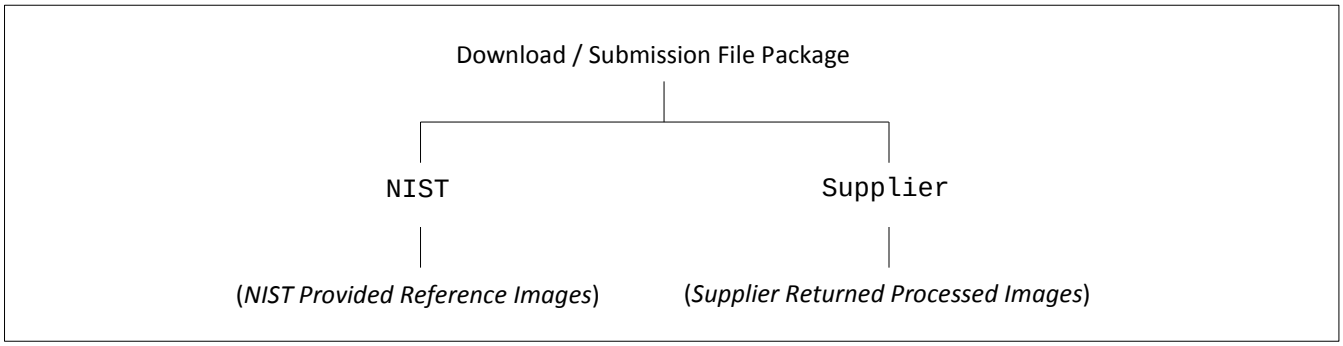

Figure 4 – Download / Submission File Package

[4] Per http://www.pkware.com/documents/casestudies/APPNOTE.TXT

5.3. Submitting Processed Images to NIST for Evaluation

Upon supplier's successful completion of the testing protocol, the `Supplier` subdirectory of the prepared file submission package (Figure 4) must contain all 44 processed files, including the 22 reference images as well as the 22 images resulting from the supplier's downsampling process. The images resulting from the supplier's downsampling process should be appended with the tag and file extension: "`-SDS.pgm`". The submission package (including the `NIST` subdirectory) must be zipped and submitted to NIST either electronically or by parcel delivery. The submission package must not contain any executable code, or macro enabled content. The submission package must not contain any proprietary or sensitive information.

Submitting Electronically

The supplier's zipped file package may be submitted to NIST by contacting the official Downsampling Test Custodian fingerprintcompression@nist.gov in order to request an account for the NIST Secure File Transfer Service (or receive alternative instructions). The email's subject line must be: "Fingerprint image downsampler conformance submittal"

Submitting Parcel Post

The supplier's zipped file package may be submitted to NIST on a data-DVD (DVD-R or DVD+R), and mailed back to NIST using the following address:

Downsampler Test Custodian
ITL-IAD-Image Group
100 Bureau Drive MS 8940
Gaithersburg, MD 20899-8940

The supplier's zipped file must not contain any binary executable code, and must not include any information deemed proprietary by the supplier. All data submitted to NIST for testing will become the property of NIST.

FBI Certification

Once the testing protocol is complete and the supplier's results satisfactorily meet the requirements set forth in this document, then NIST notifies the FBI CJIS Division that the supplier received an Overall Result of Pass. Subsequently, the FBI CJIS Division issues a letter certifying that the supplier's implementation of a downsampling code is conformant with the guidance set forth in SP 500-289. An implementation ID and a description of the supplier's submission will then be added to the current list of approved implementations maintained by the FBI.

This implementation ID will remain hard coded into the supplier solution and included in all output from the supplier CODEC according to this guidance (see section **Error! Reference source not found.**).

Note: The FBI certification for an implementation will apply only to a specific configuration. A configuration encompasses the software version of the encoder/decoder, hardware platform, operating system, and compiler used. If any of these components change resulting in a binary level change in any of the files the supplier sent to NIST for the purposes of the initial certification, then a recertification including a new implementation ID will be required.

In the case of independent or separate downsampler implementations, the FBI certification will apply to the downsampler used to reduce a 1000 ppi fingerprint image to 500 ppi. The assigned implementation ID will be entered into the comment field of the resulting file header (see Section 0).

Also note that the certification process is not intended to endorse one implementation over another, but merely to certify that the implementation meets FBI standards. The FBI does not recommend one certified implementation over another.

6. References

6.1. Publications and Reports

ISO/IEC99	ISO/IEC 8859-15:1999 - “Information technology -- 8-bit single-byte coded graphic character sets -- Part 15: Latin alphabet No. 9”. http://www.iso.org/iso/catalogue_detail?csnumber=29505 . Retrieved 03/11/2013.
JAIN	Jain, A., “Pores and Ridges: High-Resolution Fingerprint Matching Using Level 3 Features”, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 29, No. 1, January 2007.
JPEG	"T-REC-T.81 : Information technology – Digital compression and coding of continuous-tone still images – Requirements and guidelines". http://www.itu.int/rec/T-REC-T.81. Retrieved 2011-01-12.
LIBERT	“A 1D Spectral Image Validation/Verification Metric for Fingerprints”. Libert, J.M.; Grantham, J.; Orandi, S. August 19, 2009. http://www.nist.gov/customcf/get_pdf.cfm?pub_id=903078. Retrieved 2011-01-12.
NIST1	"NIST Biometric Image Software". http://Fingerprint.nist.gov/NFIS/. Retrieved 2011-01-12.
NIST2	Orandi, S., Libert, J. M., Grantham, J. D., Ko, K., Wood, S.S., Wu, J. Effects of JPEG 2000 Image Compression on 1000 ppi Fingerprint Imagery, NIST Interagency Report 7778, National Institutes of Standards and Technology, Gaithersburg, MD. http://www.nist.gov/customcf/get_pdf.cfm?pub_id=911122. Retrieved on 09/01/2012.
NIST3	Orandi, S., Libert, J., Grantham, J., Ko, K., Wood, S., Byers, F., Bandini, B., Harvey, S., Garris, M. Compression Guidance for 1000 ppi Friction Ridge Imagery, NIST Special Publication 500-289, National Institutes of Standards and Technology, Gaithersburg, MD. February, 2014. http://nvlpubs.nist.gov/nistpubs/specialpublications/NIST.SP.500-289.pdf . Retrieved on 09/15/2014
NIST4	Orandi, S., Libert, J., Grantham, J., Garris, M., Byers, F. JPEG 200 CODEC Certification Guidance for 1000 ppi Fingerprint Friction Ridge Imagery, NIST Special Publication 500-300, National Institute of Standards and Technology, Gaithersburg, MD. April 2016. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.500-300.pdf. Retrieved on 04/18/2016
NIST5	Orandi, S., Libert, J., Grantham, J., Lepley, M., Bandini, B., Ko, K.,Petersen, L. M., Wood, S., Harvey, S. “Examination of Downsampling Strategies for Converting 1000 ppi Fingerprint Imagery to 500 ppi,” NIST Interagency Report 7839, National Institute of Standards and Technology, Gaithersburg, MD, January 2013. http://nvlpubs.nist.gov/nistpubs/ir/2013/NIST.IR.7839.pdf . (Retrieved 06/16/2015)
PGM	“PGM Format Specification”. http://netpbm.sourceforge.net/doc/pgm.html. Retrieved 2015-01-23
SD27	M.D. Garris & R.M. McCabe, "NIST Special Database 27: Fingerprint Minutiae from Latent and Matching Tenprint Images," NIST Technical Report NISTIR 6534 & CD-ROM, June 2000.
WSQ	"WSQ Gray-Scale Fingerprint Image Compression Specification" Version 3.1. https://www.fbibiospecs.org/docs/WSQ_Gray-scale_Specification_Version_3_1.pdf. Retrieved 2010-01-11.

Appendix A. PGM Profile

Portable Graymap Format (PGM) is one of several image formats defined by Netpbm [PGM], an open-source programming library. PGM is a widely-supported and very straight-forward image format consisting of a small, simplified header followed by uncompressed 8- or 16-bit raw image data in ASCII or binary encodings.

A valid PGM file header always begins with a two-byte string which indicates that the file is a PGM image containing grayscale image data encoded in either ASCII ("P2") or binary ("P5"). Binary-encoded files are generally smaller in size and are preferred in most cases, including the storage of fingerprint images. The two-byte format identification string is followed by decimal values defining the width, height, and maximum gray value; each separated by whitespace characters such as spaces, tabs, carriage-returns (CRs) or line-feeds (LFs). The header is always encoded as ASCII and is terminated by a whitespace character, which also marks the beginning of the image data (which may be either ASCII- or binary-encoded). The header may also contain comments as strings beginning with the '#' character and terminated by a CR or LF character; in the context of this conformance test, the comment must contain the NIST-assigned downsampler identifier.

Table 6 – PGM File Structure and Metadata

PGM Data Field	Value	Size (Bytes)	Hexadecimal
PGM Signature	'P5 '	3	50 35 0A
Comment[5]	Comment String	variable	
Width	Image Width (pixels)	variable	
Height	Image Height (pixels)	variable	
Max Value	'255 '	4	32 35 35 0A

[5] Comment would normally be optional, but in the context of this conformance test, must contain the NIST-assigned identifier of the downsampler used in producing the file.

Appendix B. Test Image Selection Procedure

The procedures described for selection of the test image suite consider $RMSD_{SIVV}$ data vectors for images having undergone compression as well as for those subjected to downsampling only, exclusive of either JPEG 2000 compression of 1000 ppi fingerprint images or WSQ compression of 500 ppi images, whether result of downsampling or scanned comparison exemplars. While certification and conformance testing only considers the downsampler performance, NIST investigators considered it important to avoid selection of images that might exhibit anomalous results when combined with compression. As will become evident in the following, compression unavoidably increases the variability in the frequency metric chosen as a performance indicator.

The first selection was to examine the vectors of $RMSD_{SIVV}$ values to identify those images for which a minimum was found with Gaussian filtering using the parameters shown as Number 6 in Table 2 (above in Section 3.1), i.e. $\sigma = 0.8475$, $\rho = 4$ pixels. The vectors of $RMSD_{SIVV}$ values for downsampling in the context of compression and those in isolation from image compression are plotted in Figure 5 and Figure 6, respectively. It should be noted in these plots that the Gaussian parameters are designated along the abscissa only with the ordinal values 1 to 11 mapping to the Gaussian filter parameter pairs appearing in Table 2. Comparison of the two figures illustrates the greater variability of the $RMSD_{SIVV}$ profiles when evaluation is applied to downsampled images having undergone a cycle of WSQ compression.

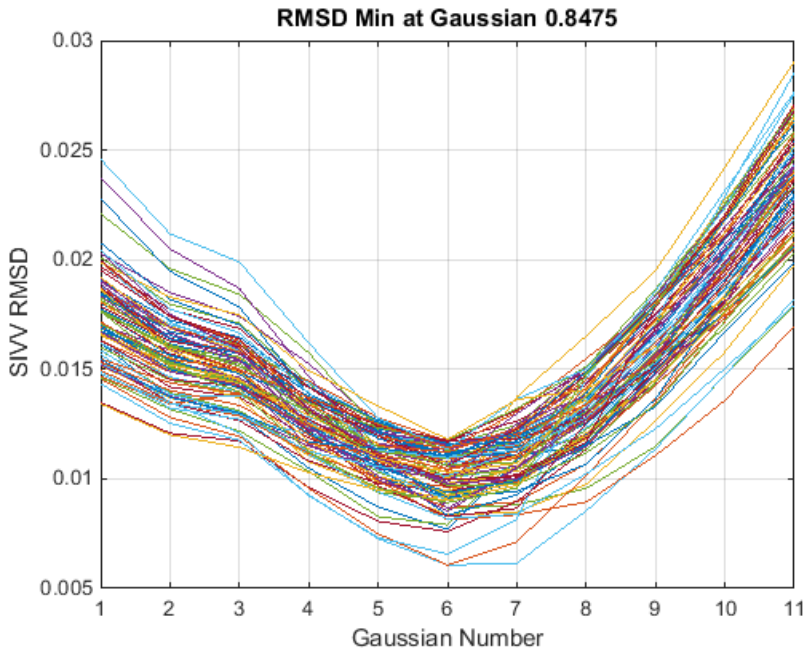

Figure 5 – Plots of $RMSD_{SIVV}$ values vs. Gaussian filter for images subjected to compressed encoding/decoding cycles with downsampling. $RMSD_{SIVV}$ vectors are selected here based on having a minimum value for Gaussian number 6, with $\sigma = 0.8475$, $\rho = 4$ pixels.

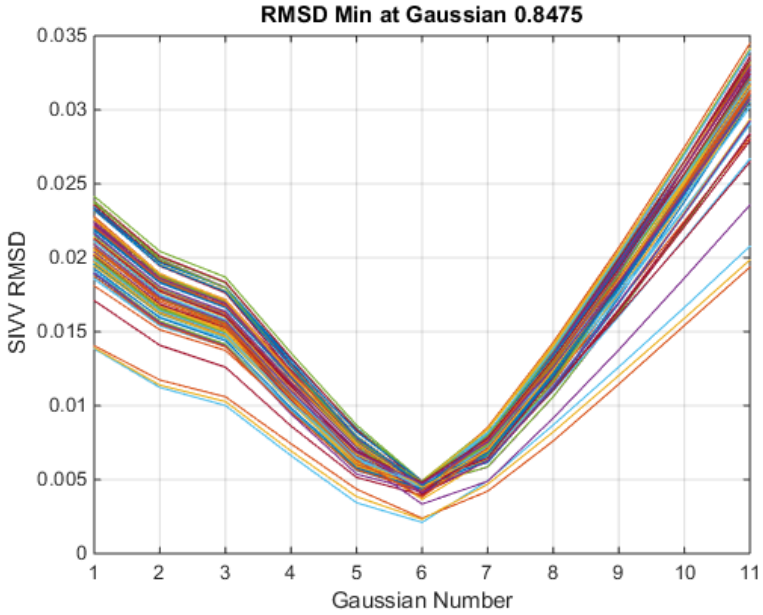

Figure 6 – Plots of $RMSD_{SIVV}$ values vs. Gaussian filter for images subjected to no compression either before or after downsampling. $RMSD_{SIVV}$ vectors are selected here based on having a minimum value for Gaussian number 6, with σ = 0.8475, ρ = 4 pixels.

These initial selection vectors were subjected to a second filtering procedure that examined the difference between the $RMSD_{SIVV}$ values obtained using Gaussian filters designated numbers 5 and 7 and that for Gaussian 6, that recommended in the Guidance. Mean and standard deviation of the differences between the $RMSD_{SIVV}$ values for Gaussian 6 and each of its neighbors was computed. A selection threshold was set via the following procedure:

Given Gaussians designated 5, 6, and 7, where Gaussian 6 is that recommended by the Guidance and for each Gaussian $RMSD_{SIVV}$ values *1…n*, where n is the number of images remaining in the set after the initial selection.

1. Compute mean $RMSD_{SIVV}$ values at Gaussian 6 ;

$$\mu_6 = \frac{1}{n}\sum_{k=1}^{n} RMSD^{6}_{SIVV_k} \qquad \textbf{(1)}$$

2. Compute mean and standard deviation of differences between RMSDSIVV values at Gaussian 6 and at neighbors 5 and 7. Operationally, we simplify the computation by first computing vectors of differences, $\mathbf{d}^{6\text{-}5}$, $\mathbf{d}^{6\text{-}7}$, the elements of which are numbered 1 to *n*

$$\begin{aligned} \mathbf{d}_k^{5-6} &= \left(RMSD^{5}_{SIVV_k} - RMSD^{6}_{SIVV_k} \right), \\ \mathbf{d}_k^{7-6} &= \left(RMSD^{7}_{SIVV_k} - RMSD^{6}_{SIVV_k} \right), \\ k &= 1...n. \end{aligned} \qquad \textbf{(2)}$$

3. Compute the mean differences in $RMSD_{SIVV}$ across the intervals between the recommended Gaussian and the nearest neighbors.

$$\mu_{6-5} = \frac{1}{n}\sum_{k=1}^{n} \mathbf{d}_k^{5-6},$$
$$\mu_{6-7} = \frac{1}{n}\sum_{k=1}^{n} \mathbf{d}_k^{7-6}. \quad \textbf{(3)}$$

4. Compute standard deviations

$$\sigma_{5-6} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(\mathbf{d}_k^{5-6} - \mu_{5-6}\right)^2},$$
$$\sigma_{7-6} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(\mathbf{d}_k^{7-6} - \mu_{7-6}\right)^2}. \quad \textbf{(4)}$$

Selection of images then consists of testing each of *k* associated $RMSD_{SIVV}$ vector against the following conditions:

$$\mathbf{t1} = \begin{cases} 1 & if\ RMSD_{SIVV}^{6} \le \mu_6 \\ 0 & Otherwise \end{cases}$$
$$\mathbf{t2} = \begin{cases} 1 & if\ d^{5-6} \ge \mu_{5-6} - \sigma^{5-6}/2 \\ 0 & Otherwise \end{cases} \quad \textbf{(5)}$$
$$\mathbf{t3} = \begin{cases} 1 & if\ d^{7-6} \ge \mu_{7-6} - \sigma^{7-6}/2 \\ 0 & Otherwise \end{cases}$$

This results in three vectors, **t1**, **t2**, and **t3**, each of length, *k*, consisting of one's and zero's. An image is chosen as a test image if all three test conditions exist, or the sum, $\mathbf{t1}_t + \mathbf{t2}_t + \mathbf{t3}_t = 3$, *t = 1…k*. As mentioned previously, this procedure was applied to both image sets having undergone compression as well as downsampling and those having sustained downsampling in isolation.

The final selection step consisted of merging the two lists of images from compression and non-compression pathways, and selecting those images appearing in both lists. Thus, whether compression is included in the processing pipeline or not, downsampling of these images according to recommendations of the NIST SP 500-289 Guidance will yield images having acceptably low RMSD values when compared to natively scanned 500 ppi images using the NIST SIVV metric.

Table 3 lists the images selected for conformance testing as described above and selected attributes. Table 7 and Table 8 are, the vectors of $RMSD_{SIVV}$ values obtained comparing non-compressed 500 ppi fingerprint impressions with corresponding downsampled 1000 ppi images in which downsampling in each case involved filtering with a Gaussian defined by one of the eleven sets of parameters shown in Table 2; Table 7 with compression and Table 8 downsampling in isolation from compression.

Table 7 – $RMSD_{SIVV}$ values for test images downsampled with filtering by each of eleven different Gaussians in the compression pathway and compared to native 500 ppi. Means and standard deviations are shown in the last two rows of the table.

Source File Name	1	2	3	4	5	6	7	8	9	10	11
003-G003_R08_F14_500_04	0.0147	0.0134	0.0139	0.0124	0.0116	0.0110	0.0117	0.0130	0.0155	0.0178	0.0211
005-G005_R08_F14_500_06	0.0165	0.0153	0.0145	0.0124	0.0109	0.0100	0.0120	0.0136	0.0162	0.0195	0.0228
018-G018_R06_F12_500_03	0.0162	0.0142	0.0137	0.0119	0.0106	0.0101	0.0111	0.0130	0.0161	0.0199	0.0236
026-G026_R09_F14_500_08	0.0152	0.0137	0.0130	0.0111	0.0096	0.0084	0.0085	0.0098	0.0127	0.0158	0.0198
031-G031_R06_F12-U255_R01_F11_500_06	0.0169	0.0153	0.0146	0.0131	0.0120	0.0115	0.0125	0.0151	0.0187	0.0224	0.0266
035-G035_R06_F12_500_02	0.0176	0.0156	0.0148	0.0122	0.0101	0.0092	0.0098	0.0121	0.0152	0.0190	0.0229
039-G039_R04_F13-U286_R06_F12_500_10	0.0170	0.0159	0.0154	0.0138	0.0121	0.0115	0.0122	0.0138	0.0166	0.0207	0.0248
057-G057_R04_F13_500_02	0.0171	0.0154	0.0146	0.0126	0.0116	0.0113	0.0122	0.0144	0.0175	0.0204	0.0238
104-B104_R08_F14_500_07	0.0167	0.0150	0.0142	0.0122	0.0122	0.0116	0.0121	0.0149	0.0184	0.0211	0.0244
107-B107_R09_F14-B108_R06_F12_500_06	0.0146	0.0132	0.0122	0.0103	0.0083	0.0079	0.0109	0.0148	0.0184	0.0225	0.0259
151-B151_R09_F14_500_08	0.0159	0.0139	0.0131	0.0112	0.0094	0.0090	0.0099	0.0123	0.0146	0.0176	0.0207
165-B165_R07_F14_500_09	0.0192	0.0169	0.0158	0.0131	0.0109	0.0092	0.0098	0.0118	0.0148	0.0184	0.0229
176-B176_R07_F14_500_03	0.0157	0.0135	0.0121	0.0092	0.0073	0.0066	0.0082	0.0146	0.0186	0.0231	0.0276
188-B188_R07_F14-B190_R08_F14_500_02	0.0188	0.0161	0.0149	0.0121	0.0097	0.0083	0.0087	0.0126	0.0153	0.0190	0.0236
194-B194_R08_F14_500_02	0.0187	0.0159	0.0145	0.0117	0.0101	0.0094	0.0106	0.0140	0.0180	0.0219	0.0271
202-U202_R08_F14_500_02	0.0199	0.0174	0.0163	0.0134	0.0119	0.0104	0.0109	0.0127	0.0156	0.0196	0.0238
202-U202_R08_F14_500_05	0.0186	0.0160	0.0149	0.0125	0.0110	0.0101	0.0110	0.0134	0.0170	0.0218	0.0265
216-U216_R04_F13_500_01	0.0184	0.0164	0.0157	0.0137	0.0118	0.0112	0.0117	0.0139	0.0178	0.0218	0.0262
222-U222_R03_F13_500_06	0.0155	0.0144	0.0139	0.0124	0.0115	0.0112	0.0123	0.0145	0.0172	0.0203	0.0240
233-U233_R06_F12_500_01	0.0177	0.0160	0.0153	0.0130	0.0110	0.0097	0.0098	0.0112	0.0134	0.0172	0.0207
288-U288_R06_F12_500_09	0.0153	0.0140	0.0134	0.0116	0.0111	0.0104	0.0113	0.0141	0.0180	0.0213	0.0258
298-U298_R02_F13_500_06	0.0176	0.0151	0.0140	0.0112	0.0096	0.0089	0.0096	0.0148	0.0179	0.0226	0.0269
Mean	**0.0170**	**0.0151**	**0.0143**	**0.0121**	**0.0106**	**0.0099**	**0.0108**	**0.0134**	**0.0165**	**0.0202**	**0.0242**
Standard Deviation	**0.0015**	**0.0012**	**0.0011**	**0.0011**	**0.0013**	**0.0013**	**0.0013**	**0.0014**	**0.0017**	**0.0020**	**0.0023**

Table 8 – $RMSD_{SIVV}$ values for test images downsampled with filtering by each of eleven different Gaussians in no compression pathway and compared to native 500 ppi. Means and standard deviations are shown in the last two rows of the table.

Source File Name	1	2	3	4	5	6	7	8	9	10	11
003-G003_R08_F14_500_04	0.0147	0.0134	0.0139	0.0124	0.0116	0.0110	0.0117	0.0130	0.0155	0.0178	0.0211
005-G005_R08_F14_500_06	0.0165	0.0153	0.0145	0.0124	0.0109	0.0100	0.0120	0.0136	0.0162	0.0195	0.0228
018-G018_R06_F12_500_03	0.0162	0.0142	0.0137	0.0119	0.0106	0.0101	0.0111	0.0130	0.0161	0.0199	0.0236
026-G026_R09_F14_500_08	0.0152	0.0137	0.0130	0.0111	0.0096	0.0084	0.0085	0.0098	0.0127	0.0158	0.0198
031-G031_R06_F12-U255_R01_F11_500_06	0.0169	0.0153	0.0146	0.0131	0.0120	0.0115	0.0125	0.0151	0.0187	0.0224	0.0266
035-G035_R06_F12_500_02	0.0176	0.0156	0.0148	0.0122	0.0101	0.0092	0.0098	0.0121	0.0152	0.0190	0.0229
039-G039_R04_F13-U286_R06_F12_500_10	0.0170	0.0159	0.0154	0.0138	0.0121	0.0115	0.0122	0.0138	0.0166	0.0207	0.0248
057-G057_R04_F13_500_02	0.0171	0.0154	0.0146	0.0126	0.0116	0.0113	0.0122	0.0144	0.0175	0.0204	0.0238
104-B104_R08_F14_500_07	0.0167	0.0150	0.0142	0.0122	0.0122	0.0116	0.0121	0.0149	0.0184	0.0211	0.0244
107-B107_R09_F14-B108_R06_F12_500_06	0.0146	0.0132	0.0122	0.0103	0.0083	0.0079	0.0109	0.0148	0.0184	0.0225	0.0259
151-B151_R09_F14_500_08	0.0159	0.0139	0.0131	0.0112	0.0094	0.0090	0.0099	0.0123	0.0146	0.0176	0.0207
165-B165_R07_F14_500_09	0.0192	0.0169	0.0158	0.0131	0.0109	0.0092	0.0098	0.0118	0.0148	0.0184	0.0229
176-B176_R07_F14_500_03	0.0157	0.0135	0.0121	0.0092	0.0073	0.0066	0.0082	0.0146	0.0186	0.0231	0.0276
188-B188_R07_F14-B190_R08_F14_500_02	0.0188	0.0161	0.0149	0.0121	0.0097	0.0083	0.0087	0.0126	0.0153	0.0190	0.0236
194-B194_R08_F14_500_02	0.0187	0.0159	0.0145	0.0117	0.0101	0.0094	0.0106	0.0140	0.0180	0.0219	0.0271
202-U202_R08_F14_500_02	0.0199	0.0174	0.0163	0.0134	0.0119	0.0104	0.0109	0.0127	0.0156	0.0196	0.0238
202-U202_R08_F14_500_05	0.0186	0.0160	0.0149	0.0125	0.0110	0.0101	0.0110	0.0134	0.0170	0.0218	0.0265
216-U216_R04_F13_500_01	0.0184	0.0164	0.0157	0.0137	0.0118	0.0112	0.0117	0.0139	0.0178	0.0218	0.0262
222-U222_R03_F13_500_06	0.0155	0.0144	0.0139	0.0124	0.0115	0.0112	0.0123	0.0145	0.0172	0.0203	0.0240
233-U233_R06_F12_500_01	0.0177	0.0160	0.0153	0.0130	0.0110	0.0097	0.0098	0.0112	0.0134	0.0172	0.0207
288-U288_R06_F12_500_09	0.0153	0.0140	0.0134	0.0116	0.0111	0.0104	0.0113	0.0141	0.0180	0.0213	0.0258
298-U298_R02_F13_500_06	0.0176	0.0151	0.0140	0.0112	0.0096	0.0089	0.0096	0.0148	0.0179	0.0226	0.0269
Mean	**0.0209**	**0.0174**	**0.0158**	**0.0111**	**0.0068**	**0.0045**	**0.0072**	**0.0124**	**0.0182**	**0.0245**	**0.0309**
Standard Deviation	**0.0013**	**0.0012**	**0.0011**	**0.0009**	**0.0007**	**0.0004**	**0.0009**	**0.0011**	**0.0015**	**0.0018**	**0.0023**

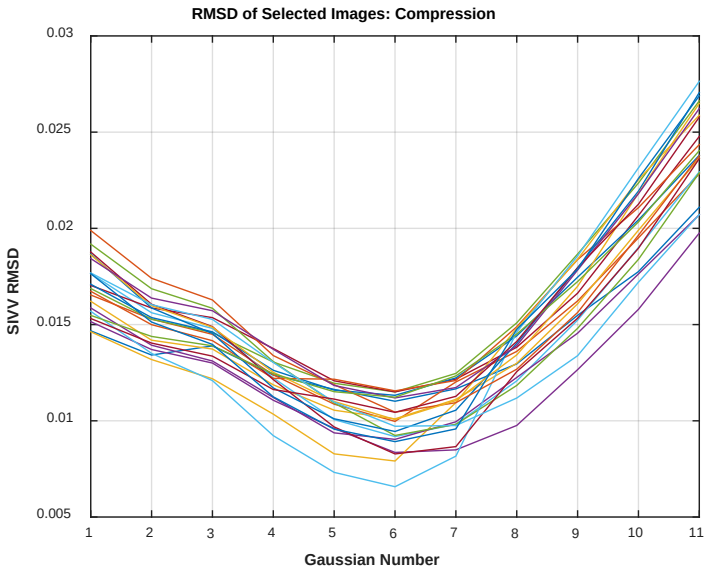

Figure 7 – $RMSD_{SIVV}$ of test image suite with WSQ compression following Gaussian filter-based downsampling.

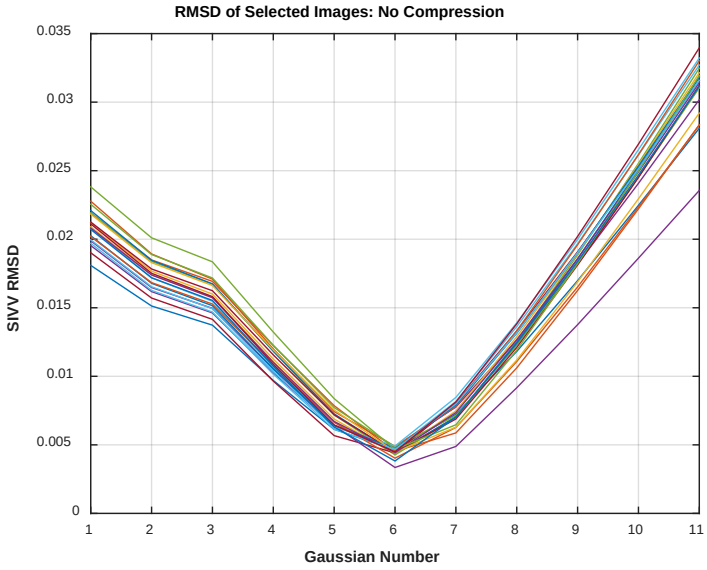

Figure 8 – $RMSD_{SIVV}$ of test image suite Gaussian filter-based downsampling with no compression.