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The FBI compression standard for digitized fingerprint images

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ABSTRACT

The FBI has formulated national standards for digitization and compression of gray-scale fingerprint images. The compression algorithm for the digitized images is based on adaptive uniform scalar quantization of a discrete wavelet transform subband decomposition, a technique referred to as the wavelet/scalar quantization method. The algorithm produces archival-quality images at compression ratios of around 15 to 1 and will allow the current database of paper fingerprint cards to be replaced by digital imagery. A compliance testing program is also being implemented to ensure high standards of image quality and interchangeability of data between different implementations. We will review the current status of the FBI standard, including the compliance testing process and the details of the first-generation encoder.

Keywords: image compression, wavelet transforms, scalar quantization, fingerprints, FBI

1 INTRODUCTION

The US Federal Bureau of Investigation (FBI) is in the process of converting its criminal fingerprint database, which currently consists of around 200 million inked fingerprint cards, to a digital electronic format. A single card contains 14 separate images: 10 rolled impressions, duplicate (flat) impressions of both thumbs, and simultaneous impressions of all of the fingers on each hand. During the scanning process, fingerprints are scanned at a spatial resolution of 500 dots per inch, with 8 bits of gray-scale resolution. (Details concerning scanning resolution requirements can be found in the ANSI standard on fingerprint data formats.[1]) Digitization thus converts a single fingerprint card into about 10 megabytes of raster image data; this, coupled with the size of the FBI's criminal fingerprint database, gives some indication of why image compression was deemed necessary for this project.

Since lossless compression of gray-scale fingerprint images[2,3] appears to be limited to compression ratios of less than 2:1, the FBI specified[4] a lossy method utilizing a wavelet transform/scalar quantization (WSQ) algorithm for the fingerprint image compression standard. The WSQ algorithm produces archival-quality images at compression ratios of about 15:1. The general structure of the compression standard is a specification of a syntax for compressed image data and a specification of a "universal" decoder capable of reconstructing compressed images produced by any compliant encoder. In particular, this implies an entire class of potential encoders, allowing flexibility for future improvements in encoder design within the constraints of the decoder specification. To date, there is but one FBI-approved encoder design.

A detailed analysis of several image compression algorithms was conducted by the FBI and documented in a subsequent paper[5] as part of the process of selecting a compression algorithm for this application. Several descriptive articles[6-9] providing overviews of the fingerprint standard have been written since the Specification was
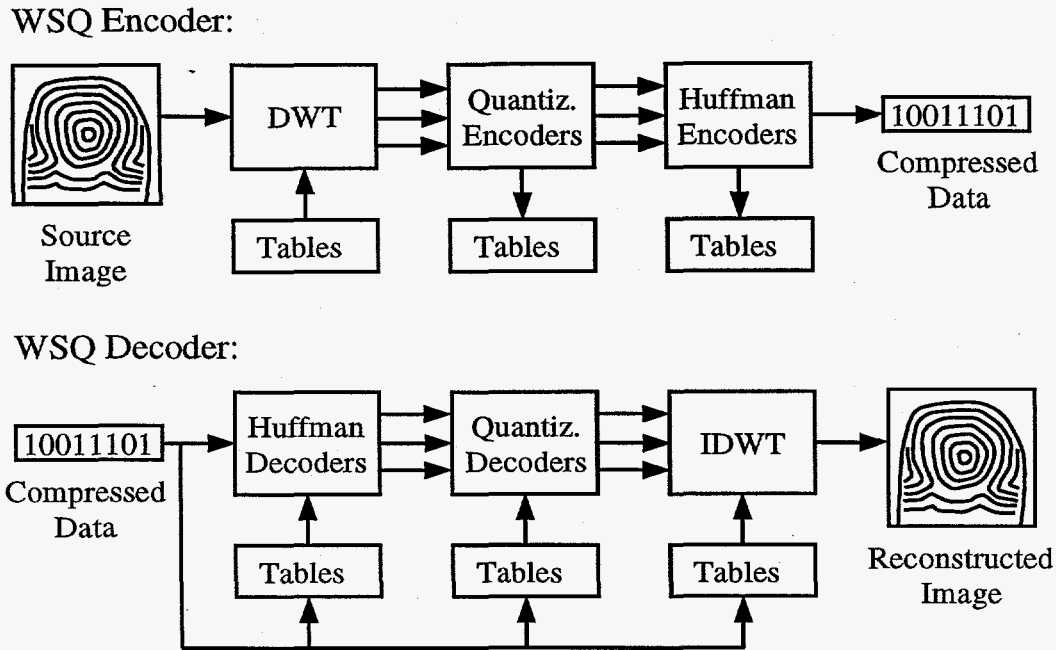
WSQ Encoder:

WSQ Decoder:

Figure 1: Overview of the WSQ algorithm.

published in the spring of 1993. Since the general (decoder) specifications have been well-documented in the works cited above, the present paper will concentrate on two areas that have not previously received adequate coverage. After a review of the decoder specifications, we will describe in detail the specifications for the first-generation WSQ encoder. Then we will outline the compliance-testing process being conducted by the National Institute of Standards and Technology (NIST) to certify compliance of implementations with the published standard.

Naturally, everything contained in this paper is descriptive only; the reader is referred to the official version of the FBI Specification[4] for normative specifications. Readers interested in seeing raster images coded according to the Specification or in retrieving electronic versions of many of the references cited in this paper are directed to the World-Wide Web pages on the subject, accessible via the URL

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`http://www.c3.lanl.gov/~brislawn`

</div>

2   THE WSQ DECODER SPECIFICATION

A high-level overview of the WSQ algorithm is depicted in Figure 1. Encoding consists of three main processes: discrete wavelet transform (DWT) decomposition, scalar quantization, and Huffman entropy coding. The WSQ decoder must in turn be capable of decoding these three processes and all variants of them that are allowed under the general Specification. This section outlines these tasks and indicates the level of generality at which they must be implemented by the WSQ decoder. As shown in Figure 1, there is certain side information, some of it image-dependent, that gets transmitted in tabular form along with the compressed data and is extracted by the decoder to enable reconstruction of the compressed image.

2.1   The DWT subband decomposition for fingerprints

The image to be compressed is decomposed into 64 spatial frequency subbands using a two-channel perfect reconstruction multirate filter bank (PR MFB), implemented in two dimensions as a separable (or product) filter bank with up to five levels of cascade.[10-12] A frequency-domain depiction of this decomposition is shown in Figure 2; note the use of unequal bandwidths, with the low and midrange frequencies partitioned into very narrow

ω_{col}

π

| 58 | 59 | 61 | 63 |

| 56 | 57 | 60 | 62 |

$\pi/2$

45	46	49	50
43	44	47	48
37	38	41	42
35	36	39	40	51	54	55

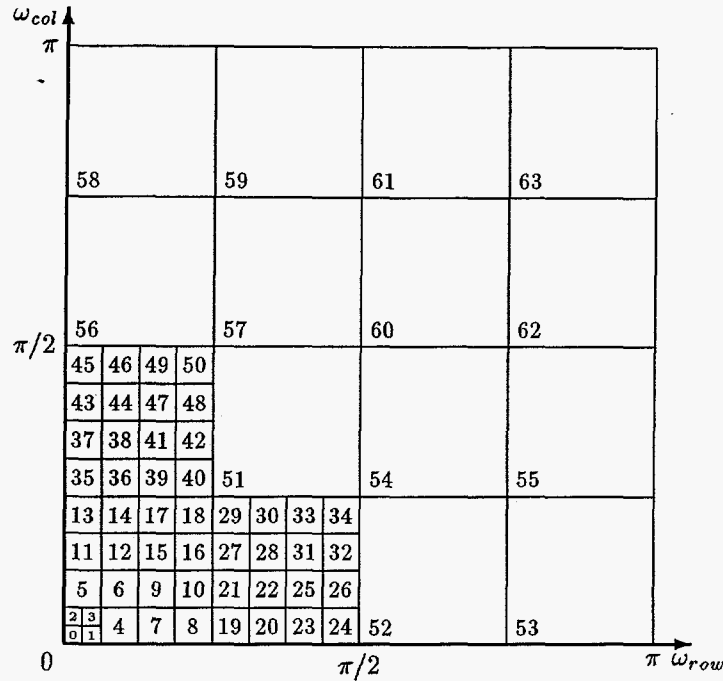| 13 | 14 | 17 | 18 | 29 | 30 | 33 | 34 |
11	12	15	16	27	28	31	32
5	6	9	10	21	22	25	26
2 3 / 0 1	4	7	8	19	20	23	24	52	53

0 $\pi/2$ π ω_{row}

Figure 2: Frequency support of DWT subbands in the WSQ Specification.

bands. This is not the familiar octave-scaled subband decomposition, and the additional frequency splittings were chosen to allow for a more flexible allocation of bits to different parts of the spatial frequency spectrum. This particular frequency partition is a fixed aspect of the Specification and must be used by all encoders. It was designed specifically for use with 500 dpi scans, which is the resolution specified in the ANSI/NIST standard.[1]

The Specification allows for the potential use of different filters in different encoders to achieve the decomposition shown in Figure 2. In particular, the Specification allows for the use of any two-channel linear phase FIR filter bank with filters up to 32 taps long. This class of PR MFB's divides up into two distinct groups: odd-length filter pairs in which both impulse responses are symmetric about their center taps (the so-called "whole-sample symmetric," or WS/WS, filter banks), and even-length filter pairs in which the lowpass impulse response is symmetric and the highpass impulse response is antisymmetric (the "half-sample symmetric/antisymmetric," or HS/HA, filter banks).

A significant issue in using filter banks for image coding is the problem of handling boundary conditions at the edges of the image. While one could simply periodize the image in both dimensions and apply the filters by circular convolution, a superior approach is to impose symmetric boundary conditions and apply the filters to the symmetrically extended image, a technique known as the symmetric extension transform (SET).[13,14] One advantage of the symmetric extension approach is that it allows images of *arbitrary* size (not just images whose dimensions are divisible by powers of 2) to be coded *nonexpansively*. This means that an $N \times M$ image is always transformed into $N \times M$ DWT coefficients, even if N or M is odd.

The two classes of PR MFB's (WS/WS and HS/HA) require slightly different symmetric extension methods to implement nonexpansive SET's, and the FBI Specification includes prescriptions for implementing both classes in WSQ coding schemes. A decoder must therefore be able to implement both classes of SET algorithms for performing the inverse DWT (IDWT) during image reconstruction. Extensive details on the implementation of SET's can be found in other papers.[13,14]

2.2 Uniform scalar quantization

Once the subbands in Figure 2 have been computed, it is necessary to quantize the resulting DWT coefficients to a relatively small number of discrete values. This is accomplished via uniform scalar quantization[15,16] with a
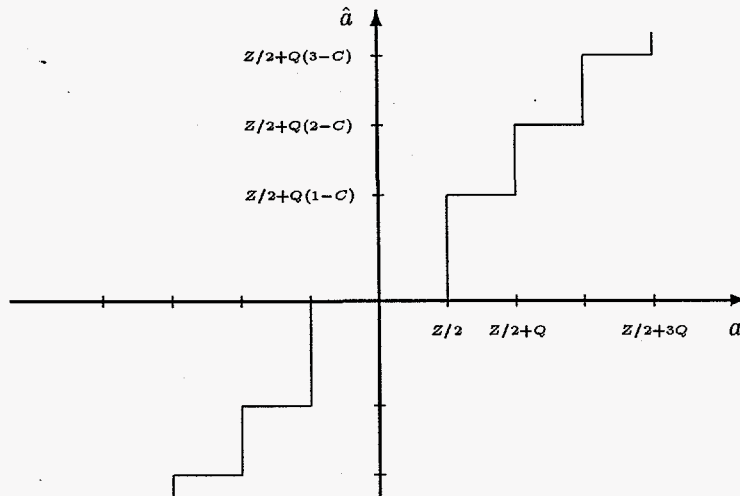
Figure 3: WSQ subband quantization characteristic.

quanitzation characteristic for each subband like the one shown in Figure 3. Several features are worth pointing out with regard to this characteristic. First, the width, Z, of the zero-bin is generally different from the width, Q, of the other bins in the quantizer, which means we need two bin widths to specify a quantizer. Second, the output levels of the quantization decoder are determined by the parameter C. Third, the mapping from floating point DWT coefficients to (integer) quantizer bin indices performed by the quantization encoder has no *a priori* bounds on its range; i.e., we do not allow for overload distortion in this quantization strategy but instead code outliers with escape sequences in the entropy coding model.

Scalar quantizers for the subbands are constructed adaptively for each image, which means that the two pertinent bin widths, Z_k and Q_k, must be transmitted for each of the 64 subbands in the quantization table accompanying each compressed image (the value C is held constant across all subbands). The decoder does not need to know how these values were determined, however, so the method of designing the 64 quantizers for each image can vary between different encoder versions. In Section 3 we will describe how this problem is solved in encoder #1.

2.3 Huffman coding and file syntax

After quantization, the subbands are concatenated into several blocks for adaptive Huffman coding. The precise partition of subbands into blocks is left up to the encoder designer, but the encoder is limited to using at least three and no more than eight blocks. The quantizer bin indices in each block are first run length coded for zero-runs and mapped to a finite alphabet of symbols. The coding model shown in Table 1 is used by all WSQ encoders; note the escape symbols for transmitting 8- or 16-bit outlying values and long zero runs. Symbol frequencies are computed in each block and Huffman codebooks are constructed following the procedures suggested in Annex K of the JPEG standard.[17,18] The BITS and HUFFVAL lists specified in the JPEG standard are transmitted as side information for each Huffman coder, and the WSQ decoder reconstructs the Huffman codebooks using the procedures of Annex C in the JPEG standard.

The syntax for writing entropy coded data and side information in the Specification is modelled closely on the syntax specified in the JPEG standard, although the structure of a WSQ image is quite a bit simpler: a single monochromatic frame with adaptive quantization and entropy coding tables but no algorithm modes or alternatives to specify. A table of DWT parameters is included since the filters may vary between encoder versions. A marker syntax is specified for parsing compressed files to locate tables and data blocks, and an option is provided for inserting restart markers into entropy coded data segments. As in JPEG, there are both interchange and abbreviated formats to allow compressed files to be written either with or without the tabulated side information. The best reference on the syntax employed in the fingerprint standard is probably the Specification document

Table 1: Huffman coding model.

Symbol	Value
1	zero run of length 1
2	zero run of length 2
3	zero run of length 3
$\vdots$	$\vdots$
100	zero run of length 100
101	escape for positive 8 bit quantizer bin index
102	escape for negative 8 bit quantizer bin index
103	escape for positive 16 bit quantizer bin index
104	escape for negative 16 bit quantizer bin index
105	escape for 8 bit zero run length
106	escape for 16 bit zero run length
107	quantizer bin index value -73
108	quantizer bin index value -72
109	quantizer bin index value -71
$\vdots$	$\vdots$
180	*Not used. Use symbol 1.*
$\vdots$	$\vdots$
253	quantizer bin index value 73
254	quantizer bin index value 74

itself,[4] although some familiarity with the JPEG standard is extremely helpful.

3 THE FIRST-GENERATION FINGERPRINT ENCODER

We now describe the encoder-specific details of the first FBI-approved fingerprint image encoder. As mentioned above, the Specification allows for multiple encoders within the framework of the fingerprint image compression standard, so any or all of the methods described in this section are subject to change in future encoder versions. To help the decoder cope with the possibility of multiple WSQ encoders, the compressed file frame header contains a parameter that identifies the encoder version used on that particular image.

3.1 Source image normalization

Before an image, $I(m,n)$, is decomposed using the DWT, it is first normalized according to the following formula:

$$I'(m,n) \ = \ \frac{I(m,n) - M}{R} \quad ,$$

where M is the image mean and

$$R \ = \ \frac{1}{128}\max(I_{max} - M, \ M - I_{min}) \quad .$$

I_{min} and I_{max} are, respectively, the minimum and maximum pixel values in the image $I(m,n)$. The main effect of this normalization is to give the lowest frequency DWT subband a mean of approximately zero. This brings the statistical distribution of quantizer bin indices for the lowest frequency subband more in line with the distributions from the other subbands in the low frequency block and facilitates compressing them with the same Huffman codebook.

Table 2: Analysis filter impulse responses for encoder #1.

Tap	Exact Value	Approx. Value
$h_0(0)$	$-5\sqrt{2}x_1(48|x_2|^2 - 16\Re e\, x_2 + 3)/32$	0.85269867900940
$h_0(\pm 1)$	$-5\sqrt{2}x_1(8|x_2|^2 - \Re e\, x_2)/8$	0.37740285561265
$h_0(\pm 2)$	$-5\sqrt{2}x_1(4|x_2|^2 + 4\Re e\, x_2 - 1)/16$	-0.11062440441842
$h_0(\pm 3)$	$-5\sqrt{2}x_1(\Re e\, x_2)/8$	-0.023849465019380
$h_0(\pm 4)$	$-5\sqrt{2}x_1/64$	0.037828455506995
$h_1(-1)$	$\sqrt{2}(6x_1 - 1)/16x_1$	0.78848561640566
$h_1(-2,0)$	$-\sqrt{2}(16x_1 - 1)/64x_1$	-0.41809227322221
$h_1(-3,1)$	$\sqrt{2}(2x_1 + 1)/32x_1$	-0.040689417609558
$h_1(-4,2)$	$-\sqrt{2}/64x_1$	0.064538882628938

$$x_1 = A + B - 1/6 \quad , \quad x_2 = -\frac{A+B}{2} - 1/6 + i\sqrt{3}(A-B)/2 \quad ,$$

$$A = \left(\frac{-14\sqrt{15} + 63}{1080\sqrt{15}}\right)^{1/3} \quad , \quad B = \left(\frac{-14\sqrt{15} - 63}{1080\sqrt{15}}\right)^{1/3} \quad .$$

3.2 First-generation wavelet filters

The analysis filter bank used in the first encoder is a WS/WS filter bank whose impulse responses have lengths of 9 taps (lowpass filter) and 7 taps (highpass filter). The impulse response taps are given in Table 2; these tap weights are transmitted as side information in compressed data files. They are implemented to compute the subband decomposition shown in Figure 2 using a symmetric extension transform. Subbands 60–63 are not computed or transmitted by encoder #1; the decoder assumes these bands have been quantized to zero.

The corresponding synthesis filters are constructed by the decoder from the transmitted analysis filters using algebraic formulas ("anti-aliasing relations") given in the Specification. More details on the anti-aliasing relations and the symmetric extension transform used with these filters can be found in the Specification and the reference paper on symmetric extension transforms.[13] The filters in Table 2 were constructed by Cohen, Daubechies, and Feauveau[19,20]; they correspond to a family of symmetric, biorthogonal wavelet functions.

3.3 Bit allocation and quantizer design

Adaptive quantization of the DWT subbands in encoder #1 is based on adaptive allocation of bits to the subbands subject to a rate-control mechanism in the form of a "target" bit rate constraint, r, that is provided by the user. The reader is referred to the authors' technical report[21] and previous research on quantizer design[22,23] for derivations.

3.3.1 Subband variance computation

A subband variance estimate is made based on a central subregion of each DWT subband. The objective is to avoid ruled lines, text and handwriting that are typically found near the borders (particularly the bottom and top edges) of fingerprint images.

Let $a_k(m, n)$ denote the floating point array of width X_k and height Y_k comprising the kth subband, indexed as $0 \leq m < Y_k$ and $0 \leq n < X_k$ with (0,0) referring to the upper left corner of the subband. The width and height

of the subregion used for the variance estimate are, respectively,

$$X'_k = \left\lfloor \frac{3X_k}{4} \right\rfloor$$

$$Y'_k = \left\lfloor \frac{7Y_k}{16} \right\rfloor \quad .$$

The variance is computed by the unbiased estimator

$$\sigma_k^2 = \frac{1}{X'_k Y'_k - 1} \sum_{n=x_{0,k}}^{x_{1,k}} \sum_{m=y_{0,k}}^{y_{1,k}} (a_k(m,n) - \mu_k)^2 \quad ,$$

where μ_k denotes the mean of a_k. The horizontal and vertical offsets for the subregion ($x_{i,k}$ and $y_{i,k}$, respectively), relative to the upper left corner, are

$$x_{0,k} = \left\lfloor \frac{X_k}{8} \right\rfloor$$

$$x_{1,k} = x_{0,k} + X'_k - 1$$

$$y_{0,k} = \left\lfloor \frac{9Y_k}{32} \right\rfloor$$

$$y_{1,k} = y_{0,k} + Y'_k - 1 \quad .$$

3.3.2 Bin width computation.

Let m_k be the factor by which the kth DWT subband has been downsampled, e.g., $m_{63} = 16$ and $m_4 = 256$. The bit rate to be assigned to the kth subband will be denoted r_k, and r will denote a "target" overall bit rate, which imposes a constraint on the subband bit rates via the relation

$$r = \sum_k \frac{r_k}{m_k} \quad .$$

For encoder #1, an appropriate value of r is specified by the FBI based on imaging system characteristics; $r = 0.75$ bpp can be regarded as a typical value, although certain systems may require higher target bit rates to achieve acceptable image quality. Typical fingerprint images coded at a target of 0.75 bpp tend to achieve about 15:1 compression on average.

The Specification allows the encoder to discard some subbands and transmit a bin width of zero ($Q_k = 0$) to signify that no compressed image data is being transmitted for subband k. For instance, this is always done for $60 \le k \le 63$ in encoder #1, and may be done for other subbands as well on an image by image basis if the encoder determines that a certain subband contains so little information that it should be discarded altogether. To keep track of the subband bit allocation, let K be the index set of all subbands assigned positive bit rates (in particular, for encoder #1, $K \subset \{0, 1, \ldots, 59\}$). The fraction of DWT coefficients being coded at positive bit rates will be denoted by S, where

$$S = \sum_{k \in K} \frac{1}{m_k} \quad .$$

To relate bit rates to quantizer bin widths, we model the data in each subband as lying in some interval of finite extent, specifically, as being contained within an interval spanning 5 standard deviations. This assumption may not be valid in general, but we will not incur overload distortion due to outliers because outliers are coded using escape sequences in the Huffman coding model. Therefore, for the sake of quantizer design we assume that the data lies in the interval $[\mu_k - \gamma\sigma_k, \ \mu_k + \gamma\sigma_k]$, where the loading factor, γ, has the value $\gamma = 2.5$. If we model the average transmission rate for a quantizer with L_k bins by

$$r_k = \log_2 L_k \quad \text{bits/sample}$$

Table 3: Subband quantizer weights A_k.

Subband	A_k
4—51	1.00
52 & 56	1.32
53 & 58	1.08
54 & 57	1.42
55 & 59	1.08

then we obtain a relation connecting bin widths and bit rates:

$$Q_k = \frac{2\gamma\sigma_k}{L_k} = \frac{2\gamma\sigma_k}{2^{r_k}} \quad .$$

Now we can present a formula for bin widths, Q_k, whose corresponding subband bit rates, r_k, satisfy the constraint imposed by r. Let Q'_k denote *relative* bin widths,

$$Q'_k = \frac{Q_k}{Q_0} = q \cdot Q_k \quad \text{with } q = Q_0^{-1} \quad ,$$

which can be regarded as "weights" related to the relative allocation of bits. The parameter q is a constant related to the absolute overall bit rate of the quantizer system. The weights chosen by the FBI are

$$Q'_k = \begin{cases} 1 , & 0 \leq k \leq 3 , \\ \frac{10}{A_k \log_e(\sigma_k^2)} , & 4 \leq k \leq 59 , \end{cases}$$

where the constants A_k are given in Table 3. Note that the weights, Q'_k, are image-dependent (since σ_k^2 is the variance of the kth subband), which means that this quantization strategy is employing an image-dependent bit allocation.

To achieve effective rate control, it remains to relate the parameter q to the overall target bit rate. It can be shown[22,23] that if one uses the value

$$q = \gamma^{-1}2^{r/S-1}\left[\prod_{k \in K}\left(\frac{\sigma_k}{Q'_k}\right)^{1/m_k}\right]^{-1/S} \quad .$$

then the resulting quantizer system corresponds to a bit allocation satisfying a target bit rate constraint of r bpp. The effectiveness of this rate control mechanism in practice has been documented by the first two authors,[22] who have also shown that this quantizer design can be interpreted as an optimal bit allocation with respect to an image-dependent weighted mean-square distortion metric.

Two cases require special attention. First, to prevent overflow if $\log_e(\sigma_k^2) \approx 0$, the encoder discards any subband for which $\sigma_k^2 < 1.01$ and sets $Q_k = 0$. Second, if $Q_k > 2\gamma\sigma_k$ then the above quantization model implies that $r_k < 0$. Since this is not physically meaningful, we use an iterative procedure to determine q. The iterative procedure excludes from the bit allocation those subbands that have theoretically nonpositive bit rates; this will ensure that the overall bit rate constraint, r, is met. Once q has been determined, bin widths are computed and quantization performed for all nondiscarded subbands, including those with theoretically negative bit rates. While we expect that quantization of bands with negative bit allocations will produce essentially zero bits, it may nonetheless happen that a few samples in such bands actually get mapped to nonzero values by quantization and therefore contribute information to the reconstructed image.

For all subbands, the zero bin width, Z_k, is computed in terms of Q_k by the formula

$$Z_k = 1.2\,Q_k \quad ,$$

and the parameter determining the quantization decoder output levels is set to $C = 0.44$.

Iterative Procedure for Computing Bin Widths.

1. Initialize:

   (a) $j = 0$;

   (b) $K^{(0)} = \{k \mid 0 \le k \le 59 \text{ and } \sigma_k^2 \ge 1.01\}$.

2. Iterate on j to calculate q:

   (a) $S^{(j)} = \displaystyle\sum_{k \in K^{(j)}} \frac{1}{m_k}$;

   (b) $q^{(j)} = \gamma^{-1} 2^{r/S^{(j)} - 1} \left[\displaystyle\prod_{k \in K^{(j)}} \left(\frac{\sigma_k}{Q'_k} \right)^{1/m_k} \right]^{-1/S^{(j)}}$.

3. Exclude bands that would contribute theoretically nonpositive bit rates:

   (a) $\Xi^{(j)} = \left\{ k \in K^{(j)} \mid Q'_k/q^{(j)} \ge 2\gamma\sigma_k \right\}$.

   (b) If $\Xi^{(j)} \ne \emptyset$ then

         i. $K^{(j+1)} = K^{(j)} \backslash \Xi^{(j)}$,

         ii. $j = j + 1$,

         iii. go to step 2;

      else

         i. $q = q^{(j)}$,

         ii. $K = K^{(j)}$,

         iii. continue.

4. Calculate bin widths:

       If $k \in K^{(0)}$ then

           $Q_k = Q'_k/q$

       else

           $Q_k = 0$.

5. Exit.

The backslash $\backslash$ denotes the set difference operator; i.e., $A \backslash B = A \cap B^c$.

3.4   Huffman coding blocks

The subbands produced by encoder #1 are divided into three blocks for Huffman coding, with one Huffman encoder constructed for block 1 (subbands 0 through 18) and a second Huffman encoder constructed for use on both blocks 2 and 3 (subbands 19–51 and 52–59, respectively).

A change has been made recently in the range of symbols used for these two Huffman coders. The Specification originally restricted the set of symbols used in the two Huffman coders based on the sets of quantizer bin indices and zero run lengths expected in images coded at around 0.75 bpp. These restrictions have been dropped, however, since it was discovered that some systems need to operate at significantly higher bit rates to produce acceptable image quality. Both Huffman coders in encoder #1 therefore now make use of the entire symbol alphabet in Table 1.

4   WSQ COMPLIANCE CERTIFICATION

Commercial vendors who wish to do so can have their implementations tested and certified as complying with the FBI WSQ Specification. In this section we outline the certification process and describe the results to date.

Compliance tests are given in the Specification[4] for both encoder and decoder implementations. The implementor obtains a suite of test files via ftp, processes them, and then supplies an 8mm or quarter-inch cartridge tape to the FBI containing the compressed files (for encoder testing) or reconstructed files (for decoder testing). The FBI sends the tape to NIST, where the files are tested against a reference WSQ implementation for compliance with the Specification. Test results are returned to the FBI, which then grants or denies the implementor WSQ Compliance Certification.

4.1   Encoder compliance measures

At present, all encoders must comply with the Specifications for encoder #1, which was described in Section 3. (Note that an implementation of encoder #1 need only perform the DWT decomposition with the 9-tap/7-tap filter bank specified for encoder #1, whereas a decoder must be able to implement the full range of potential transforms encompassed by the Specification.) The implementor is given 19 test images of various sizes (including odd-dimensioned images, e.g., 539×651 pixels) to encode at target bit rates of 0.75 and 2.25 bpp. The encoder compliance measures in the Specification[4] can be summarized as follows:

1. The compressed file size (excluding comments) must be within 0.4% of the reference compressed file size.

2. All quantization bin widths (including the zero bins) must be within 0.051% of the corresponding bin widths produced by the reference encoder.

3. At least 99.99% of the bin index values must be the same as the corresponding values produced by the reference encoder, and no bin index value may differ from the reference value by more than 1.

Measure 1 is a quick check to verify that the implementation being tested comes very close to matching the compression performance of the reference encoder at the target bit rates. Measure 2 verifies that the implementation being tested is performing the adaptive scalar quantizer design and bit allocation correctly. Measure 3 involves examining the values output by the quantization encoder (the bin index values) and performing two separate accuracy tests: first, at least 99.99% of the bin index values must be *identical* to the output of the reference quantization encoder, and second, the quantization encoder being tested can't differ from the output of the reference encoder by more than 1 bin on any one DWT coefficient. Finally, in addition to the specified compliance measures, the NIST examiner has also been visually inspecting the images reconstructed from the compressed files under test to spot-check for obvious image fidelity problems.

No particular tests are specified for the Huffman encoder or the compressed file syntax *per se*, but the reference decoder must be able to parse the compressed files submitted on tape, construct the Huffman, quantization

and IDWT decoders, and decode the compressed files in order for the examiner to perform the above encoder compliance tests. This provides some measure of testing of the Huffman encoder and the compressed file syntax. Moreover, Measure 1 detects appreciable deviations of Huffman compression performance from that of the reference encoder. There also are no explicit tests of the implementation of the forward DWT, but experience has shown that implementations with faulty DWT's (often mistakes in the performance of the symmetric boundary extension algorithms) fall far short of complying with the accuracy tests specified in Measure 3, and fairly small deviations of the floating point subband variances from those produced by the reference encoder are sufficient to cause the adaptive bit allocation and quantizer design to fail the tests of Measure 2.

4.2   Decoder compliance measures

While a WSQ decoder doesn't have to perform bit allocation or compute Huffman symbol statistics, it does have to implement a wide range of synthesis filter banks. For decoder compliance testing, the implementor is given compressed test image files to decode; six of these compressed images have been transformed using filter banks different from the 9-tap/7-tap filter bank specified for encoder #1, including some with even-length filters. The decoder being tested must identify the filter types and construct the synthesis filters from the parameters provided in the transform table and then implement the appropriate boundary extention operations for the IDWT. The only decoder compliance measure given in the Specification[4] is:

1. At least 99.9% of the reconstructed (pixel) values must be the same as the corresponding values produced by the reference decoder, and no reconstructed values may differ from the reference reconstructed image by more than 1 (gray level).

Although this measure doesn't target any specific decoding tasks, it is stringent enough to catch mistakes made anywhere in the decoding process. Note that the only sources of noise or uncertainty expected in the decoding process are floating point truncation in the quantization decoder and the IDWT, and this noise level should be extremely low given the small number of floating point operations performed per pixel in quantization decoding and the IDWT.

4.3   Compliance performance by commercial implementations

As of the date of this writing, six commercial vendors (and one government agency) have submitted over two dozen different WSQ encoder or decoder implementations for certification. While some errors have been uncovered during testing and some implementations have required more than one examination before passing, all parties to date that have applied for certification have eventually passed the compliance tests.

5   CONCLUSIONS

We have described the current state of development of the FBI's WSQ Gray-Scale Fingerprint Image Compression Specification, paying particular attention to details specific to the first-generation encoder. To date, we have seen that commercial vendors have been very successful at obtaining WSQ Compliance Certification by passing the compliance tests conducted by NIST. As the criminal justice community converts over to this new electronic format, we expect it to facilitate significant improvements in the utilization of fingerprint identification services.

6   REFERENCES

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