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Fingerprint Recompression after Segmentation

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Abstract

With the increasing availability and usage of flat multi-finger collection systems, fingerprint identification is increasingly being performed from segmented data and frequently these segmented areas are recompressed to generate a 10-print file with separate records for each finger. Since recompression often incurs further loss, the amount and type of recompression can impact the extracted features and match scores. In this study several different WSQ-based cropping recompression alternatives are compared to each other by match score impact, crop and recompression speed, and output file size.

Two new WSQ recompression methods one aimed at high quality and one at very high speed are briefly described and compared with more typical WSQ 15:1 recompression. The study indicates that both of the new methods maintain better match quality than WSQ 15:1.

KEYWORDS: fingerprint, WSQ, recompression, segmentation, speed, quality

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1 Introduction

With the increasing availability and usage of flat multi-finger collection systems, fingerprint identification is increasingly being performed from segmented data and frequently these segmented areas are recompressed to generate a 10-print file with separate records for each finger. Since recompression often incurs some further loss, the amount and type of recompression can impact the extracted features and match scores.

All legacy systems readily read and process single finger files in WSQ [1] format and WSQ is the only lossy compression approved for use on 500 ppi fingerprints. In this study several different WSQ-based cropping recompression alternatives are compared to each other and also compared with no recompression. Comparisons are made by match score, crop and recompression speed, and output file size. These results may help in choosing the appropriate recompression (if any) within the context of a global system design.

The recompression methods included in this study are: standard WSQ 15:1, and two new WSQ-based crop/recompress techniques first discussed in [2], namely Static-Q and CropCoeff. Static-Q is a high quality recompression approach that is similar in speed to standard WSQ. CropCoeff is much faster in execution but suffers somewhat in image quality near the edge of the recompressed image. Both Static-Q and CropCoeff impose a slight limit on the placement of the upper left corner during cropping.

This study is a first look at whether the quality of CropCoeff is high enough to be used in place of WSQ 15:1 recompression when processing speed and CPU load are important considerations. When CPU load is not a problem, Static-Q may be a preferable crop/recompress alternative.

2 Experimental Setup

2.1 Data

Two sets of EFTS [3] documents were used: Test Identification (ID) flat files which generated the probe data, and Match files which became the verification gallery. The original WSQ compression goal and settings used to generate these files are unknown. These are the same files that were used for the "Fingerprint Segmentation Boundary Placement" study [4].

93 *ID flat* files were processed, each containing three type-14 image records (a 4-finger slap for each hand, and one image with both thumbs). These files were chosen at random from a set of nearly 2000 flats. Each image record also contained a segmentation box for each finger position present. These source-proposed segmentation boxes were manually altered (visually) to create tangent boxes. During overall generic testing, the tangent boxes were used. This was followed up with more focused testing on the source-proposed boxes alone.

One or more Match files existed for each ID flat. The *Match files* were complete10-finger files (10 type-4 single image records as well as the flats). Only rolled image data was used for the Match files. Approximately 50% of the Match files are labeled as livescan data and the rest are inked card scans.

The 10-print files that CJIS created from the original ID flat files were located. The single finger images in these files were cropped from the flats and compressing with WSQ at some ratio, averaging about 15:1.

2.2 Processing

The ID files were processed to allow each fingerprint to be matched. This processing involved a combination of decompression, segmentation, recompression and feature extraction. A generic flowchart is shown in Figure 1. The following sections provide more detail.

The single fingers within the CJIS files were also decompressed and matched. Since CJIS had already performed their own segmentation and recompression, those processing stages were omitted.

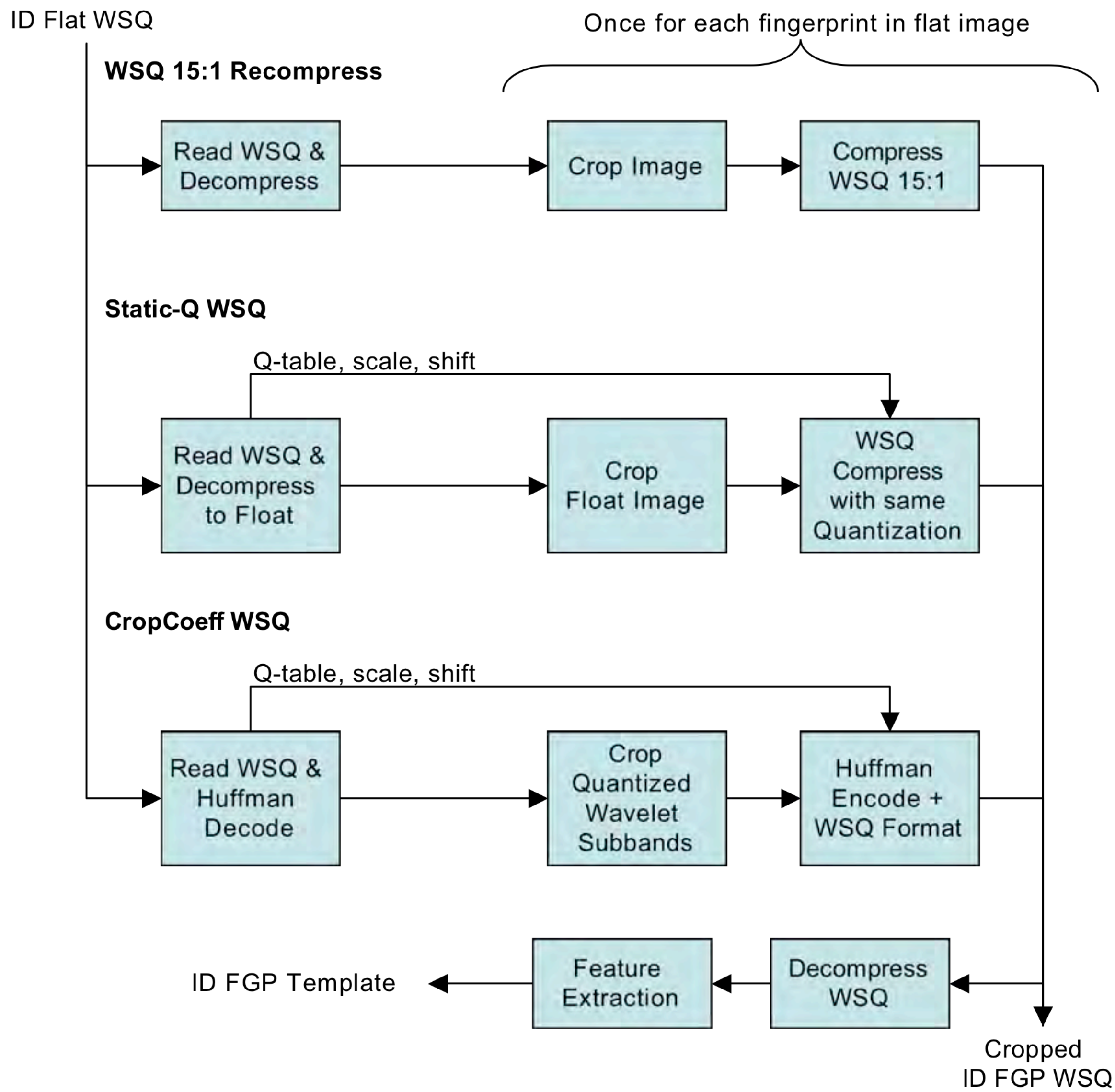

Figure 1. ID file pre-match flowchart.

2.2.1 Decompression

WSQ decompression when required was performed using the NIST NFIS2 [5] WSQ library. The new images after appropriate decompression / segmentation / recompression and final decompression were directly input into the VeriFinger feature extractor with no intervening file. VeriFinger was given no indication that the images were lossy and included subtle WSQ artifacts.

2.2.2 Segmentation

Each ID flat card was marked into 10 separate print requests using the tangent box plus extra user-specified border at the sides. Negative border requests caused the segmentation boundary to move inward from the tangent box by that number of pixels, while positive borders moved the boundary outward. In addition to the extra border, the upper left (UL) corner of the requested crop box was moved to the closest non-negative multiple of 32 rows and columns. For example, a UL corner request of (63,140) would move to (64,128). The UL corner movement is a requirement for Static-Q or CropCoeff usage. The lower right corner had no extra movement beyond any initial extra border request. All corners of the crop box were forced to remain on original image. The UL corner movement was also used by WSQ 15:1 for purposes of direct comparison.

Extra side border amounts ranged from -64 to 128 pixels. To limit the number of study variables the top and bottom extra border was fixed: +16 for the top border and 0 for the bottom border. The multiple border amounts made it easier to spot consistent quality trends.

Match features were extracted from the entire decompressed rolled images within the Match files, without any manual cropping or recompression. These are the same feature files used in the “Fingerprint Segmentation Boundary Placement” study.

2.2.3 Recompression

WSQ 15:1 recompression was performed using the NIST NFIS2 cwsq with a “ –r” setting of 0.75. Alterations to the NIST NFIS2 WSQ library were used to create the Static-Q and CropCoeff functionality, mostly via removing or cutting and pasting appropriate sections of code. Figure 2 shows image results from the 3 methods and the Static-Q and CropCoeff techniques are briefly described here:

Static-Q WSQ: The image is decoded to floating point (without applying the final scale/shift operation), and cropped with the upper left corner at a multiple of 32 rows and columns. This cropped data is recompressed (omitting the scale/shift operation) using the original Q-tables. The original WSQ quantization parameters (scale, shift, Q-tables) are written in the Static-Q WSQ file.

CropCoeff WSQ: The original WSQ file is Huffman decoded to form quantized wavelet subbands. Each subband is cropped to only contain coefficients pertaining to the crop area, which must have its upper left corner at a multiple of 32 rows and columns. The smaller set of coefficients is Huffman encoded as in a WSQ compliant compressor. The original WSQ quantization parameters (scale, shift, Q-tables) are written in the CropCoeff WSQ file.

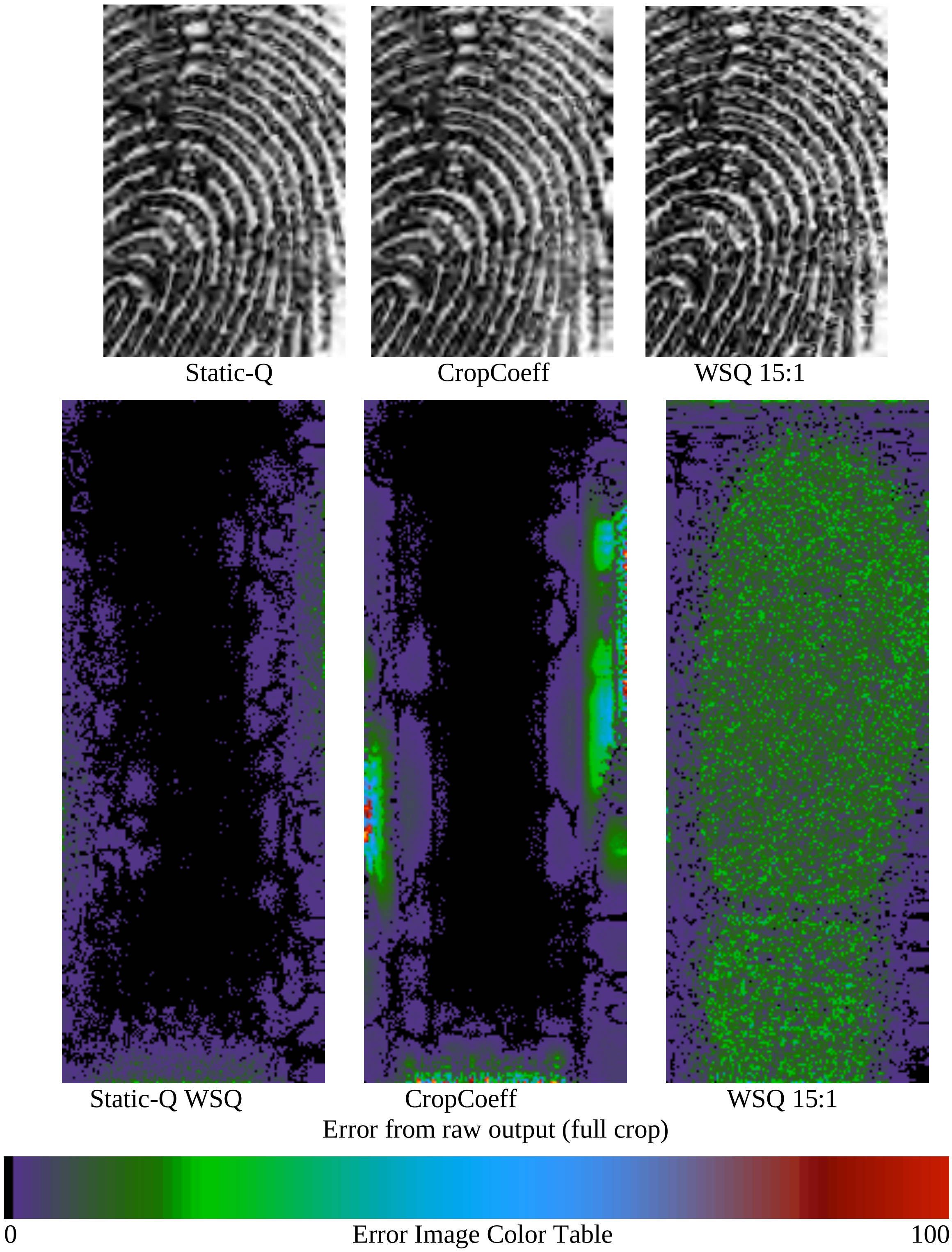

Figure 2. Image comparison of alternative output formats.[1]

[1] At top of the figure are extracts of the cropped image at the right border. Note visible CropCoeff degradation at far right edge and increased artifacts throughout WSQ 15:1. Since the images are very similar, error images highlight pixels varying from the original decompression. The top crop border corresponds to the original image boundary, so CropCoeff and Static-Q WSQ maintain accuracy right up to that edge.

Both Static-Q and CropCoeff begin and end with a correctly formatted WSQ file. They have no active control of the recompressed file size or quality, but instead try to maintain the original WSQ file quality. In the central region of the cropped area they both are identical to the original WSQ, but close to the edges CropCoeff can have a large quality loss. Static-Q creates image data that can be examined prior to making crop decisions. CropCoeff never creates an image, so crop area placement is an external input (or derived only from quantized wavelet coefficients).

2.2.4 Match Processing

Feature extraction and match score computation was performed using the Neurotechnologija VeriFinger 5.0.2.2 SDK [6] in general mode (no specific tuning to scanner type). The inexpensive Neurotechnologija matcher has performed reasonably well in past NIST tests and was easy to integrate in current software.

Features were extracted once from the rolled prints in the Match files and stored. For the ID files, features were extracted from different recompressions at multiple segmentation boundaries and match scores were computed against all appropriate Match files (sometimes more than one).

Only index and middle fingers as well as thumbs were scored since ring and little fingers are rarely matched. Combined this created n=1019 match pairs.

2.3 Information Collected

Overall processing time was recorded during ID flat file segmentation. For every fingerprint segmentation, crop dimensions and output WSQ file size were recorded. For each ID / Match print pair the match score was recorded for different recompressions and when possible different side border sizes. The default VeriFinger threshold of 50 was used, i.e. any match score initially computed as lower than 50 was reported as 0.

3 Analysis

In this section the processing speed, output file size, and match processing impact are examined. Due to the nature of the test (short time scale, manual pre-processing) the number of cases is not large enough for a FAR analysis. Instead average match scores are computed with the understanding that they can hide important sub-effects. The ‘borderline’ and non-match scores are examined in more detail to see if any unusual patterns appear.

3.1 Computation Speed

Since CropCoeff does not perform any of the quantization or wavelet transform processing it runs considerably faster than Static-Q or WSQ 15:1. Static-Q eliminates a few minor processing steps, so runs a hair faster than WSQ 15:1. No recompression avoids the recompression stage, but still needs to decode the original image, so is considerably slower than CropCoeff. Figure 3 shows timing results as measured on a MacOSX Dual 1.25 GHz PowerPC G4 given in seconds per Mpixel (i.e. 10^6 pixels). The pixel count included total pixels in the input images and the cropped output images, and was in the range 5 - 9 x 10^6. These execution times were quite stable across all the files (see 1 sigma error bars).

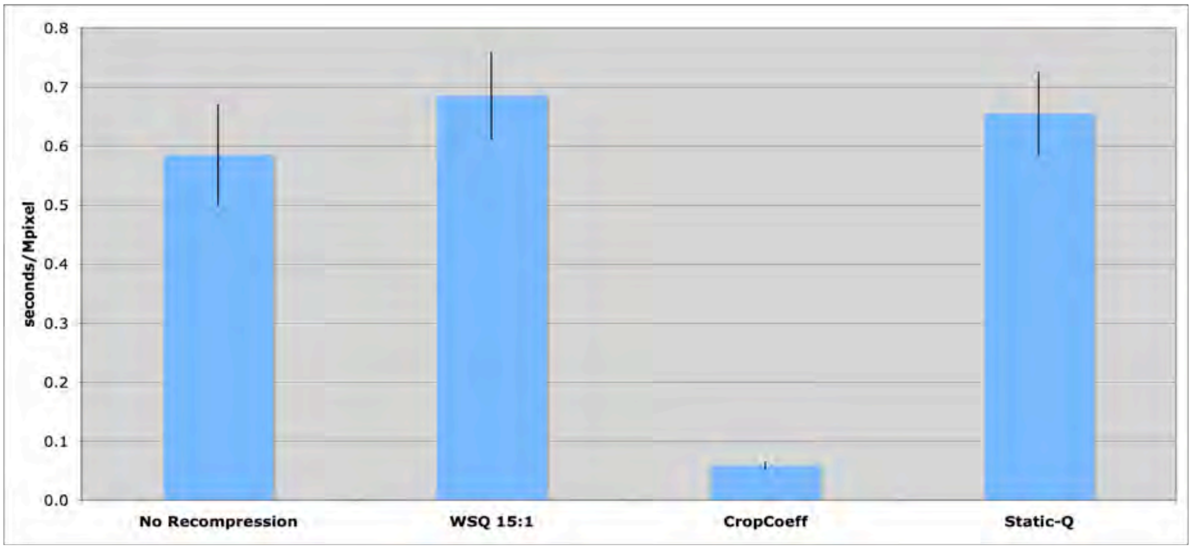

Figure 3. Computation time by recompression type. Error bar = 1σ.

The numbers include time for reading the multi-finger flat images once and then cropping, recompression, and writing individual WSQ files for all 10 fingers. Under these conditions CropCoeff is more than 10 times faster than WSQ 15:1. A simpler CropCoeff implementation, which Huffman decodes the entire image for each fingerprint extracted is still 5 times faster than the fastest WSQ 15:1 implementation.

3.2 Tangent Box Analysis

Initially segmentation was performed using a variety of side border sizes, so that the difference in the recompression scores could be seen in context with other effects. Only the ID flats could be processed this way, as the CJIS data was already segmented. A later section shows results when the source-proposed segmentation is used.

3.2.1 Average Match Scores

Previous results [4] suggest that moving the upper left corner to align with a 32x32 grid location will not significantly alter the match score. To confirm this we compare no recompression match scores both with and without UL corner movement in Figure 4. The two curves are nearly identical.

Figure 5 shows the average scores for the different recompression techniques compared to the average scores when no recompression is applied. All the crop boxes in this case had UL corners aligned on the 32x32 grid.

The average match scores hide considerable variation on individual fingerprints. For example, WSQ 15:1 achieves scores that are sometimes better and sometimes worse than the other methods. Figure 6 shows the how much the individual recompression scores vary from the score achieved without recompression.

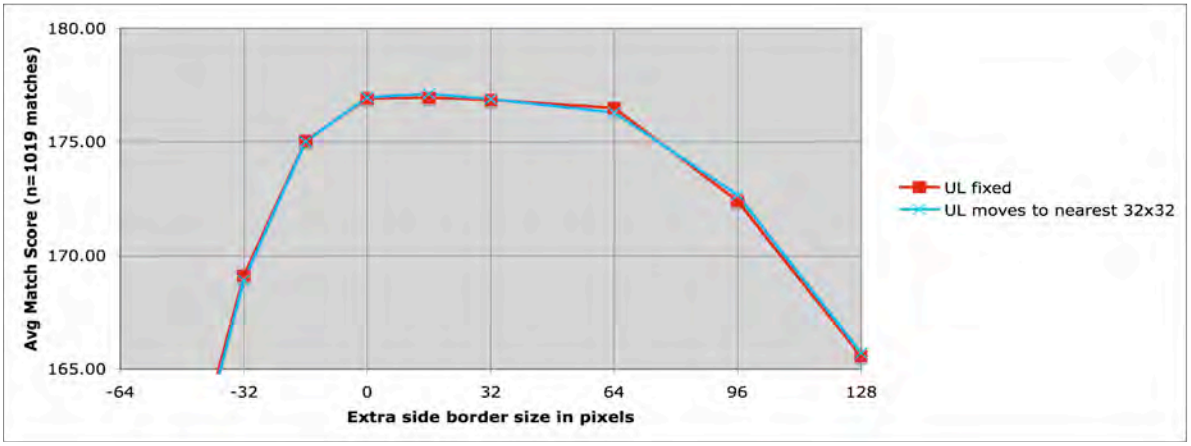

Figure 4. Average match score with and without UL corner alignment to 32x32 grid.

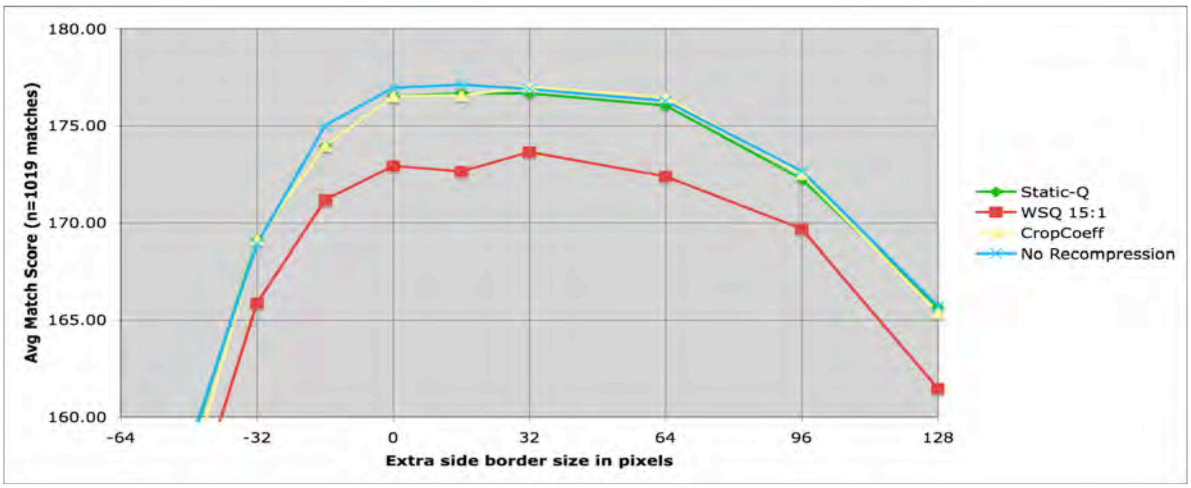

Figure 5. Average match score reaction to different recompression techniques.

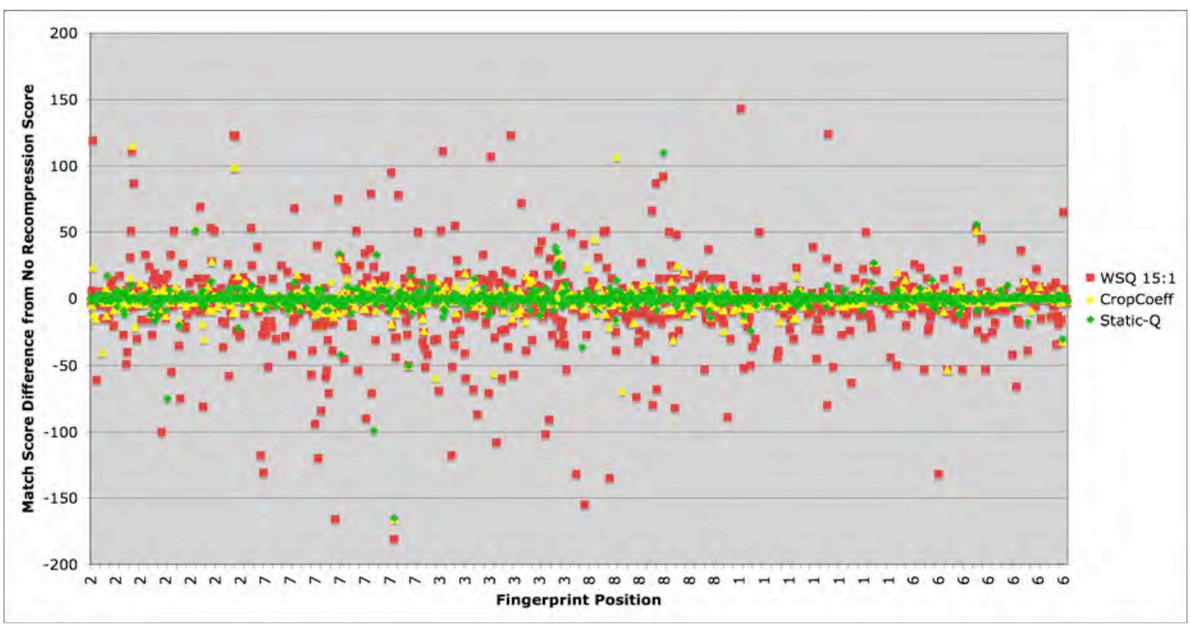

Figure 6. Individual recompression match scores relative to no recompression.

3.2.2 Borderline Match Inspections

Although the average match scores suggest CropCoeff works better than WSQ 15:1 and as well as Static-Q, there is an underlying concern that averaging may be hiding borderline match effects. Increases in already healthy match scores might be swamping losses in the lower scores.

Figure 7 gives a first look at the number of unsuccessful verifications versus recompression type. Often verifications were unsuccessful due to poor quality in the rolled match print,[2] but in a few cases a different recompression changed the verification result. Although the dataset is too small to draw any significant conclusions, this plot also suggests that CropCoeff and Static-Q are out-performing WSQ 15:1.

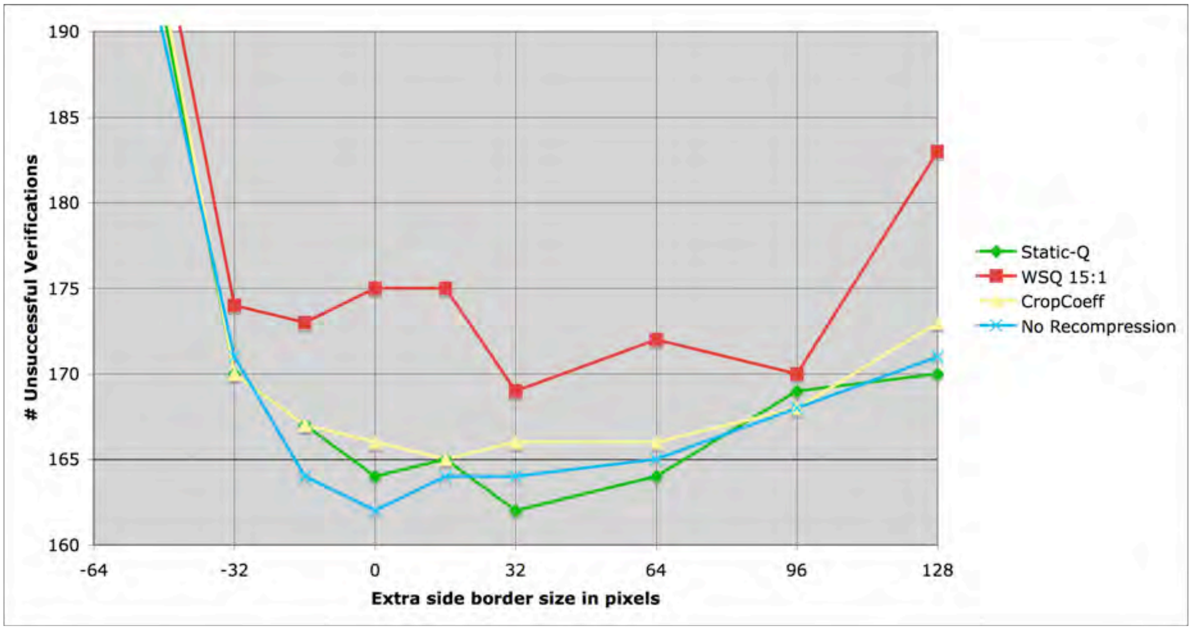

Figure 7. Number of unsuccessful verifications by recompression type.

3.3 Source-Proposed Segmentation Boxes

In this section, the most likely usage scenario is examined, with the original source-proposed boxes guiding the segmentation.

These boxes are generally a bit wider than the tangent box (average 34 pixels to either side), but as was seen in the previous section that has very little impact on the match performance. The top border is often above the top tangent, except on thumbs where it is often below the top of the print. There does not appear to be a consistent pattern in the bottom (crease) edge placement. Overall the height of this box had some very large variations from the tangent box height.

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[2] No attempt was made to eliminate Match files/prints of low quality. Often several Match files were present for the same individual, some at low quality and others higher quality. Because of this, the percentage of missed verifications (~16%) is quite high.

The UL corner of this box is moved to the closest multiple of 32x32 to accommodate CropCoeff and Static-Q, but the lower right corner remains in place. WSQ 15:1 was run both with and without the UL corner adjustment, but there was no appreciable difference in the results.

3.3.1 CJIS Segmentation

The size of the CJIS generated single-finger images was discovered to be identical to the source-proposed box in nearly all cases. Two mis-segmentations and one good segmentation on very faint data were replaced by ‘no image provided’. Therefore we conclude that CJIS is using the source-proposed segmentation boxes, and the results can be directly compared to ID flat processing using these same boxes.

3.3.2 Match Scores

No extra border is added to these segmentation boxes; only a single average point is generated for each method. Figure 8 shows the average scores for each technique. Figure 9 shows the number of unsuccessful verifications. CJIS recompression has higher quality than the test WSQ 15:1 but still does not achieve scores that are as high as CropCoeff.

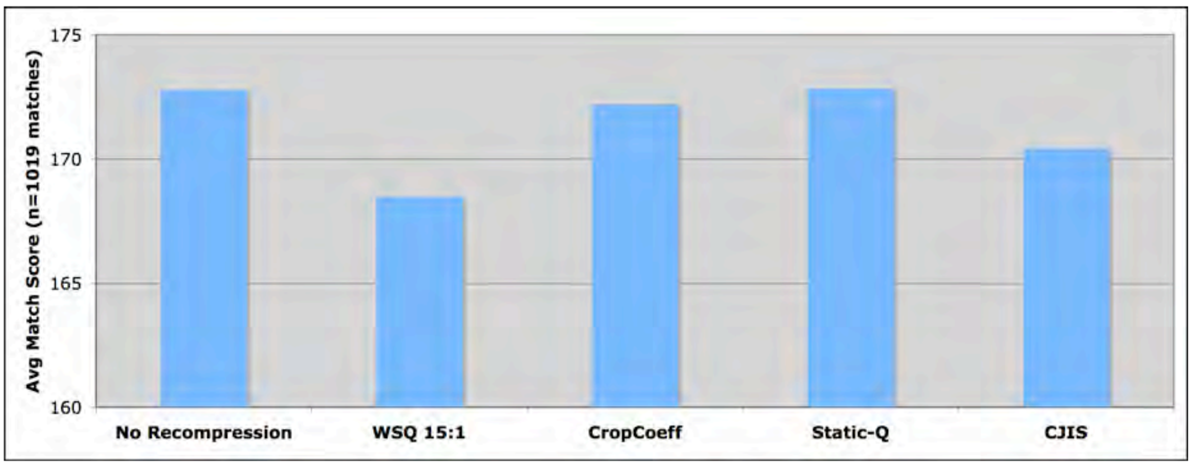

Figure 8. Average match score by recompression type on source boxes.

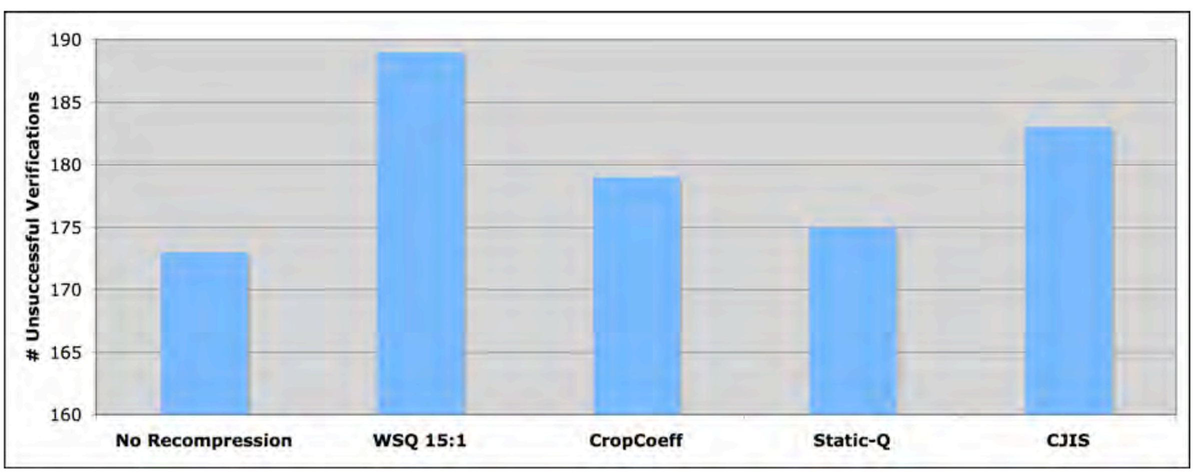

Figure 9. Missed verification by recompression type on source boxes.

3.4 Recompressed Sizes

Figure 10 shows the average compression ratio for the original multi-finger WSQs and the new single finger recompressed WSQs separated by recompression method. Notice that the CJIS recompression is approximately 15:1 but has much larger standard deviation than WSQ 15:1. Due to the large error bars, these averages are very deceptive. The original compression ratio is highly variable and as we will see CropCoeff, Static-Q and CJIS recompression are sensitive to those variations while WSQ 15:1 is not.

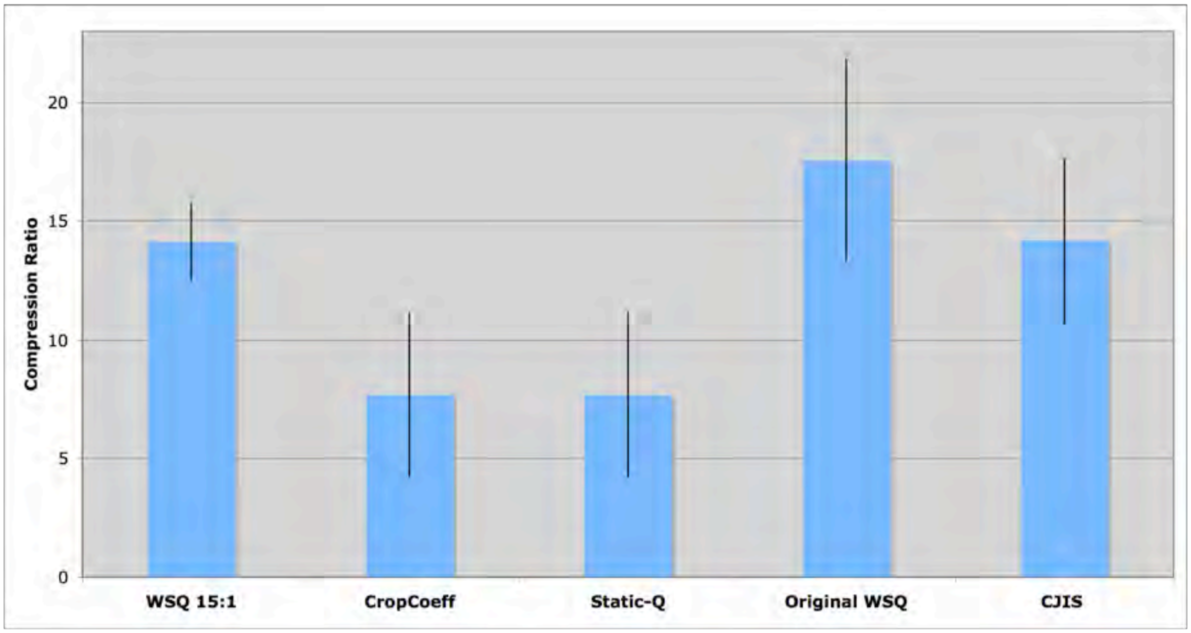

Figure 10. Average compression ratios. Error bar = 1σ.

The original file compression ratios range from 10:1 to 40:1 due to differences in image content, and more importantly different originator WSQ rate settings. The original WSQs are expected to have a large compression ratio due to the large amount of highly compressible uniform background. The actual fingerprint area is expected to have a lower compression rate as is borne out in the average CropCoeff ratio. Figure 11 shows the original compression ratios as a function of the equipment used to generate the ID files, while Table 1 provides a quick summary of the capture equipment.

Table 1. Image Capture Equipment identified in ID files.

Source Provider	Model	# Files
Smiths Heimann Biometrics, GmbH	LS2-Check	33
Cogent Systems, Inc.	LS2-Check	33
Cross Match Technologies, Inc.	Guardian	5
Identix Corp.	TP-4x4A	5
Identix Corp.	TP-3000	2
Smiths Heimann Biometrics, GmbH	Lite-X	4
ChoicePoint Inc.	EAF8.0.7.4	1

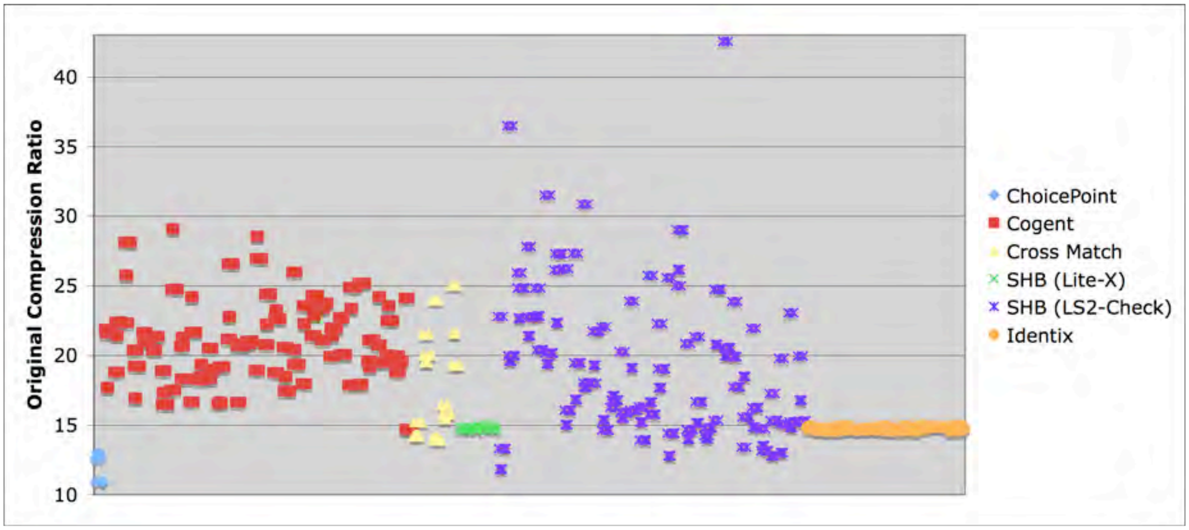

Figure 11. Compression ratio generated by equipment.

All Identix files and Smith Heimann Biometrics Lite-X files have original compression ratios very close to 15:1. We suspect these devices tune WSQ settings on an image-by-image basis to achieve 15:1 compression. A fair number of the Cross Match and Smith Heimann Biometrics LS2-Check files have an average compression ratio near 15:1, which may be due to average multi-finger image parameter tuning. The ChoicePoint compression is much lower, suggesting parameters that are tuned for 10:1. Such tuning of compression parameters based upon full multi-finger flat images is liable to produce files that are large. In contrast the Cogent data appears to have been compressed using parameters very similar to those used for WSQ 15:1 in this experiment.

WSQ 15:1 recompression makes no effort to maintain the quality already present in the file, but instead recompresses using a constant rate control. Figure 12 shows the results. The compression ratios are consistent and do not vary based upon source provider.

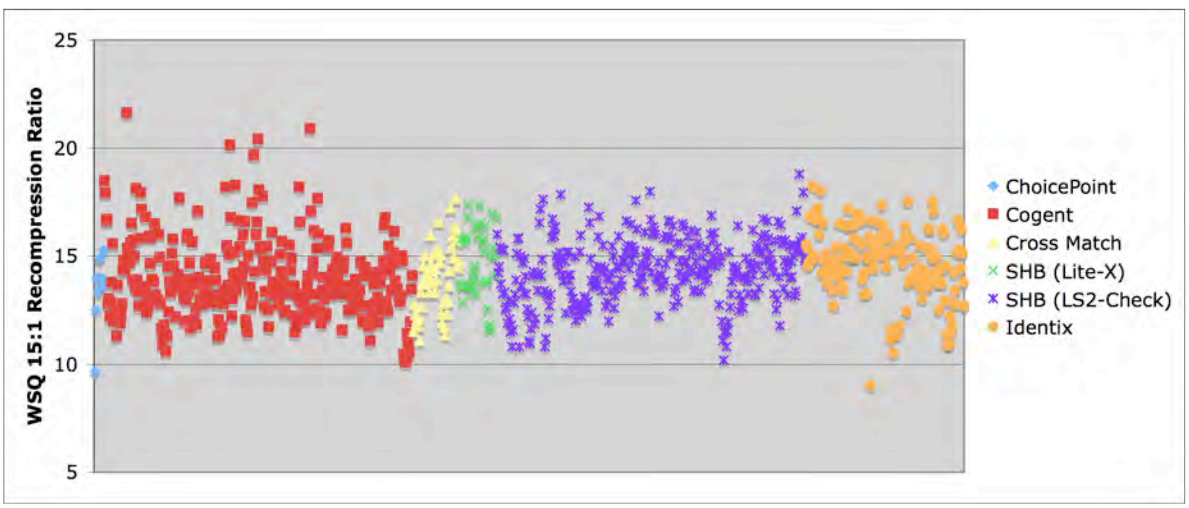

Figure 12. WSQ 15:1 recompression ratios.

By contrast the CJIS recompression shown in Figure 13 appears adjustable. The Cogent files are not as heavily recompressed as many of the other files. They might be using 10:1 compression on heavily compressed files, and 15:1 compression on files that are very lightly compressed. This helps avoid the recompression errors that occur when 15:1 compression is reapplied to a fingerprint and would account for the improved match scores.

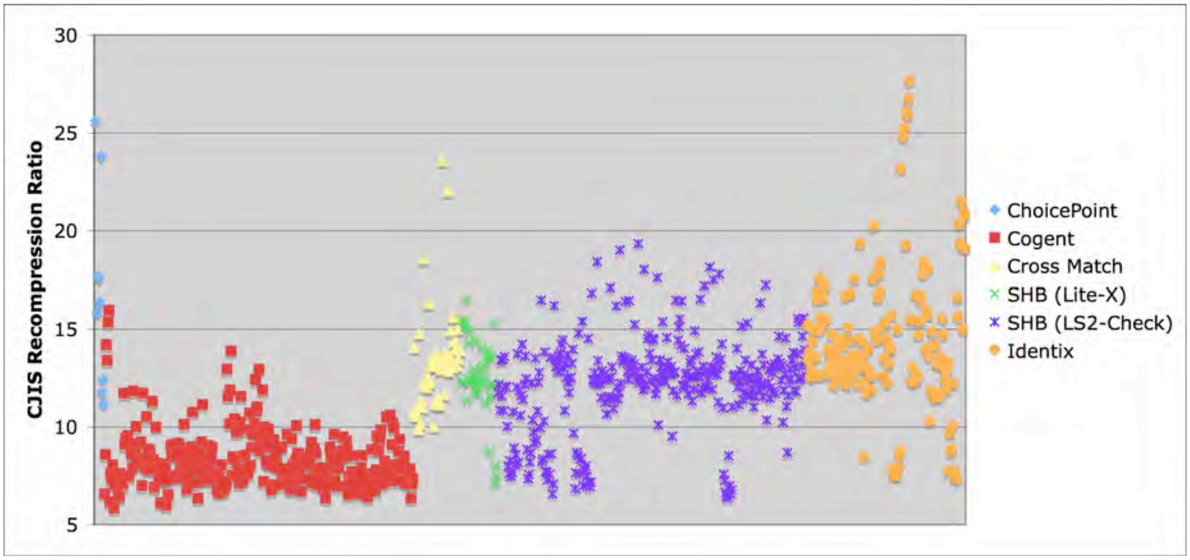

Figure 13. CJIS recompression ratios.

When the data is recompressed with CropCoeff, the original compression ratio is considerably reduced, but the original image quality in the central portion of the fingerprint is maintained. Figure 14 shows the CropCoeff recompression ratios. They are in the vicinity of 5:1 for almost all the providers except Cogent, suggesting that other providers are either under compressing the data or generating higher accuracy data, depending upon your perspective.

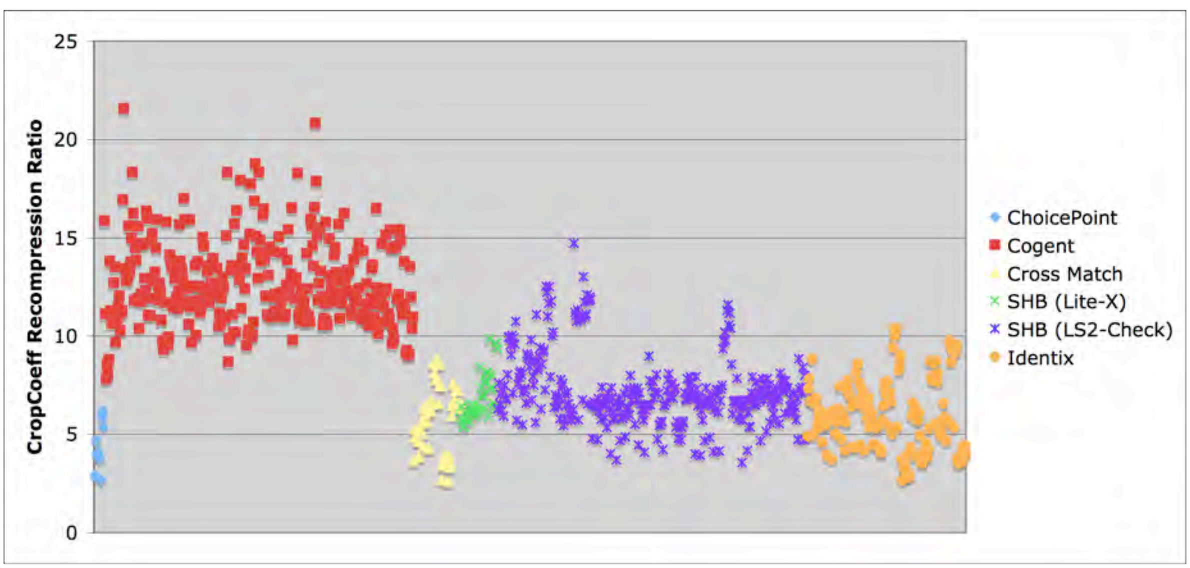

Figure 14. CropCoeff recompression ratios.

Since the CropCoeff and Static-Q files were frequently larger than the WSQ 15:1 files it is not surprising that their matching performance is better. Further examination using only files generated by Cogent would provide a more accurate assessment of quality differences when the output file sizes are similar.

4 Observations

Although the number of samples is not large enough to make iron clad statements, the trends are clear.

1. Both CropCoeff and Static-Q out-perform both WSQ 15:1 and the current CJIS recompression.
2. Static-Q and CropCoeff are closer in performance to the original compressed data than WSQ 15:1. This can be seen not only in the error images, but also by examining the variance of match scores compared to a no recompression alternative.
3. CropCoeff is much faster than other WSQ recompression alternatives.
4. Static-Q and CropCoeff files vary in size based upon the original compression parameters. If the original data is compressed using parameters tuned for single finger images, then the recompressed file sizes will be close to WSQ 15:1 recompression. If instead the original parameters are tuned to achieve a 15:1 compression ratio on multi-finger flats, then the CropCoeff and Static-Q files will be larger than a WSQ 15:1 recompression.
5. Static-Q has better quality near the edge of the crop area. CropCoeff creates noticeable image changes within 4 pixels of the crop border.
6. CropCoeff and Static-Q maintain interior image quality close to the original compression without requiring any parameter tuning.

A large part of the quality improvement seen for CropCoeff comes from extra quality transmitted in the original file. When possible CropCoeff or Static-Q should be used to ensure that the full quality is maintained in the cropped file. If limiting the output file size beyond what can originally be achieved via Static-Q or CropCoeff is important, then two approaches are possible.

1. Recompress with WSQ at a dialed in rate (for example 15:1), and live with the quality reduction it produces.
2. Request the original file be generated with a higher compression ratio, so that the actual compression ratio in the fingerprint area more closely approximates the desired compression. While less obvious as a solution, this approach has two benefits: a) the original file is smaller and can be transmitted faster, and b) the data suffers less recompression loss when CropCoeff or Static-Q is used.

References

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Glossary

Abbreviations/Acronyms

CJIS	Criminal Justice Information Services
CPU	Central Processing Unit
FBI	Federal Bureau of Investigation
NFIS	NIST Fingerprint Image Software
NIST	National Institute of Standards and Technology
ppi	Pixels per Inch
SDK	Software Development Kit
UL	upper left
WSQ	FBI's Wavelet Scalar Quantization fingerprint compression format

Terms

Compression ratio	Raw image size / compressed image size
CropCoeff	Very fast WSQ recompression technique
Error image	Absolute difference from baseline image
Flat print	4-finger or 2-thumb plain impression
Feature extractor	Finds minutia, ridge counts, and other features used in fingerprint identification.
Inked	Image acquired on card stock and later digitally scanned
Lossy	Causing a change in some pixel values
Lossless	Causing no change in pixel values
Livescan	Fingerprint image acquired originally via digital means
Static-Q	High quality WSQ recompression technique
WSQ 15:1	Results of using NFIS2 'cwsq –r 0.75'