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MITRE

Test Procedures for Verifying IAFIS Image Quality Requirements for Fingerprint Scanners and Printers, v1.5

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ABSTRACT

The Integrated Automated Fingerprint Identification System (IAFIS) is a national fingerprint and criminal history system maintained by the Federal Bureau of Investigation (FBI), Criminal Justice Information Services (CJIS) Division. The IAFIS provides automated fingerprint and latent print search capabilities, digital image storage, and transmission of fingerprints and query responses. The fingerprints and corresponding criminal history information are submitted voluntarily by state, local, and federal law enforcement agencies. IAFIS incorporates fingerprint capture devices (scanners) and fingerprint printers, either of which can affect the image quality of fingerprint images that are processed through the system. The FBI has therefore established an IAFIS Image Quality Specification in order to define the quantitative image quality requirements for these devices.

This document delineates the test procedures used to verify compliance of fingerprint capture devices and printers with the IAFIS Image Quality Specification. It is intended to support procurements and in-house development efforts throughout the criminal justice community and, through the corresponding FBI product certification program, promote and enhance interoperability between all IAFIS participants.

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DOCUMENT CHANGE HISTORY

Date	Document Number	Version[1]	Description of Change[2]
October 2016	MTR 05B0016R9	v1.5	Minimum dimensions for FAP 50 increased.
February 2016	MTR 05B0016R8	v1.4	Update to sponsor contact [Eric M. Phillips] and update to reference new 50 card test deck.
February 2013	MTR 05B0016R7	v1.4	This document, completed by M.A. Lepley, C. F. Bas, and T.M. Nanez, modifies Section 7 related to Stress Imagery captures and Environmental Information.
May 2012	MTR 05B0016R6	v1.3	Update to sponsor contact [Eric M. Phillips]
April 2012	MTR 05B0016R5	v1.3	This document adds additional procedures related to stress imagery and inked card comparisons.
June 2011 (dated 9/2010)	MTR 05B0016R4	v1.2	Update to sponsor contact [Frederick B. Jaco]
September 2010	MTR 05B0016R3	v1.2	Update to sponsor contact [John M. Manzo]
March 2010	MTR 05B0016R2	v1.2	Revision by C.F. Bas, added technical content to Section 4 related to Fingerprint Printers.
September 2008	MTR 05B0016R1	v1.1	Revision completed by M.A. Lepley, based upon revisions started by N.B. Nill. Update to sponsor contact [B. Scott Swann]
April 2005	MTR 05B0000016	N/A	*Test Procedures for Verifying IAFIS Scanner Image Quality Requirements for Fingerprint Scanners and Printers*, by N. B. Nill. An extensive revision of the 1994 MITRE document: MP 94B0000039R1
November 1994	MP 94B0000039 R1	N/A	*Test Procedures for Verifying IAFIS Scanner Image Quality Requirements*, by R.D. Forkert, G.T. Kearnan, N.B. Nill, and P.N. Topiwala. In addition to the above MITRE documents, this document formed the basis of the 1995 FBI document: *Test Procedures for Verifying IAFIS Scanner Image Quality Requirements*, FBI document number CJIS-TD-0110, March 1995.

[1] Version number is only increased upon a change in technical content.

[2] More recent versions of the document supersede earlier versions.

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SECTION 1

INTRODUCTION

This document presents the test procedures that are used to verify the FBI's Integrated Automated Fingerprint Identification System's (IAFIS) Image Quality Specifications (IQS), as defined in Appendix F of [EBTS]. The IQS applies to: (1) systems which scan and capture fingerprints[3] in digital, softcopy form, including hardcopy scanners such as ten-print card scanners and latent print scanners, and live scan devices, altogether called "fingerprint scanners"; and (2) systems utilizing a printer to print digital fingerprint images onto paper or card stock, called "fingerprint printers".

The terms "paper scanner" and "live scanner" are used in this document to refer to the two basic types of fingerprint scan/capture devices. The hardcopy input to a paper scanner is a fingerprint on a reflective paper substrate, such as an inked fingerprint on card stock, or a latent print on photographic paper. In a live scanner, fingerprints are directly captured from a subject's fingers and output in digital form. When the term "scanner" is used in this document with no qualifier, it refers to both paper scanners and live scanners.

Verification of compliance of a scanner or printer to the full set of IQS requirements is primarily performed by the *test method*; i.e., verification through systematic exercising of the item with sufficient instrumentation to show compliance with the specified quantitative criteria. A few requirements are verified by the *inspection method*; i.e., verification of requirements by visual examination of the item or review of descriptive documentation.

The requirements for Fast Track certification testing are a subset of the full testing described in this document; they are described in section 6. Data requests that either fall outside the current requirements or only apply in very specific instances are documented in section 7.

General Test Attributes

• All required testing is the responsibility of the vendor who is seeking certification.

• All testing should be performed on a single, representative unit of the product/model for which certification is being sought. The test unit should be operated in its normal

[3] The term "fingerprint" in this document may also include palmprint, whole hand print, or a print from another part of the human body.

operating mode, to the degree consistent with obtaining the test images[4]. For example, a scanner should not be tested at slower than normal operating speeds to meet geometric accuracy requirements.

• For scanner testing, the digital test images are to be supplied in an uncompressed format such as raw, TIFF, or PGM formats, at 8 bits per pixel (8 bpp or 256 gray-levels). Do not submit compressed images and do not supply uncompressed images that were previously compressed via a lossy compression; e.g., do not supply images that are decompressed WSQ images.

• The vendor is encouraged to analyze its test data results before submitting the test data to the FBI; test data analysis software (freeware) is available through the FBI for this purpose (IQS Test Tools CD). The vendor has the option of submitting its test results and any additional information, such as discussion of results or technical/design information on the device that is relevant to the testing. The vendor also has the option to utilize its own test analysis software, or modify the FBI-supplied software. However, the vendor should expect that an independent analysis of the test data will be performed by the FBI or its supporting organizations. Therefore, the test images (for scanner) or test prints (for printer) must be submitted to the FBI. Analysis by the FBI or its supporting organizations will primarily rely on the same IQS Test Tools that are made available to the vendor.

• If the test data analysis by the FBI or its supporting organizations indicates noncompliance with any of the IQS requirements, the vendor will be informed of the specific deficiencies and given an opportunity to correct the deficiencies and submit new test data.

• If the vendor has good reason to believe that certain test procedures given in this document are not applicable to the vendor's device, or cannot be applied without modifying the device, or if other test procedures the vendor has confidence in can be shown to be equivalent to the test procedures given in this document and are better suited to testing the particular device, then the vendor may initiate communications with the FBI in this regard, which may result in acceptable modified, device-tailored test procedures. Potential test modifications are particularly relevant to livescan devices; refer to Appendix A - Livescan Testing Notes.

[4] However, the "adaptive processing" that may be applied to fingerprint capture (IQS section 2.6) should not be applied when scanning test targets. If, due to device design features, it is necessary to apply fingerprint adaptive processing to the test target scans, the adaptivity (settings, level) must be invariant over the entire scanned area of the test target.

Test Targets

Following is a listing of the commonly used scanner test targets; refer to Appendix B - Commercial Sources for Targets, for obtaining these targets.

• Multiple parallel bar target at 1.0 cycles per millimeter (cy/mm) for geometric accuracy and pixels per inch resolution tests.

• Sine wave target with gray patches for Modulation Transfer Function (MTF) and linearity tests.

• Uniform dark gray and light gray targets for signal-to-noise ratio and gray-level uniformity.

Scanner testing also includes scanning a set of fingerprints. For paper scanners, a specific test set of inked fingerprint cards is supplied by the FBI. For live scanners, the vendor is responsible for supplying a set of livescans.

Fingerprint printers are tested with a digital test target and a set of digitized test fingerprints; both of these are on the IQS Test Tools CD.

Image Capture Areas

At a minimum, a ten-print card scanner shall be capable of capturing an area of at least 5.0 x 8.0 inches, which captures all 14 printblocks, either each printblock as a separate image, or all printblocks together as a single image. Figure 1-1 shows the standard ten-print applicant fingerprint card, FD-258, with dimensions of major components[5]. When a specific test procedure in this document refers to a "5 x 8 inch scan area", it is referring to the 14 print block area, as illustrated in Figure 1-1.

[5] The older FD-249 card has the same overall size and printblock dimensions as FD-258, but a different format/layout for the text blocks.

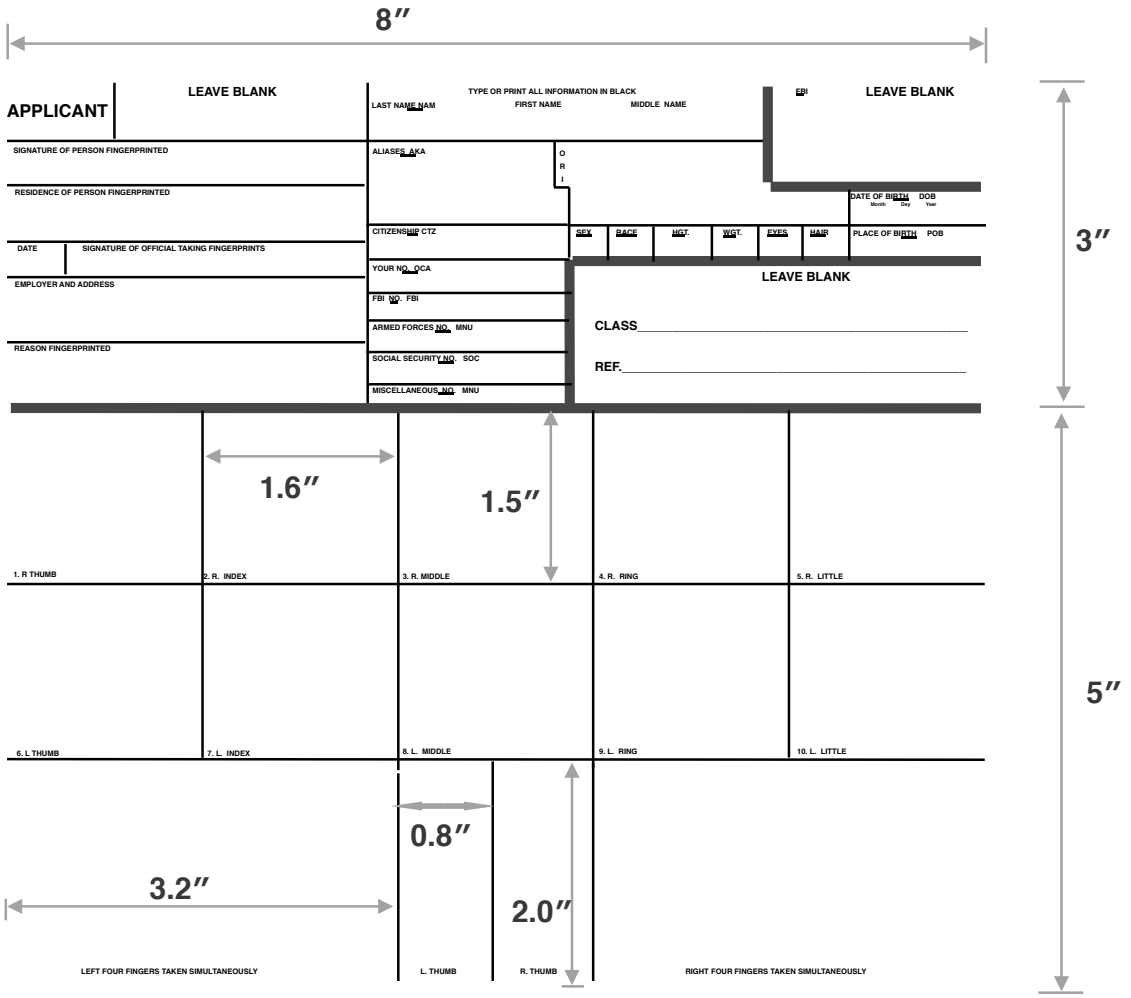

Figure 1-1. Standard Ten-Print Fingerprint Card (FD-258)

In terms of individual printblocks, Table 1-1 gives the preferred capture sizes, applicable to both card scan and live scan systems [EBTS, ANSI/NIST], with the exception that, when scanning fingerprint cards, the card form dimensions take precedence.

Table 1-1. Preferred Capture Sizes

	Preferred Width (inches)	Preferred Height (inches)
roll finger	1.6*	1.5
plain thumb	1.0	2.0
plain 4-fingers (sequence check)	3.2	2.0
plain 4-fingers (identification flat)	3.2	3.0
full palm	5.5	8.0
half palm**	5.5	5.5
writer's palm	1.75	5.0

* A live scanner must be capable of capturing at least 80% of full roll arc length, where full roll arc length is defined as arc length from nail edge-to-nail edge.
** Although larger sizes are preferred, minimum acceptable half-palm dimensions are 5.0 x 5.0 inches.

Image Gray-Level Quantization

The final output of all test target scans and all test (and operational) fingerprint scans, shall be gray-level quantized to 8 bpp (256 gray-levels).

Point-of-Contact

Questions or concerns regarding the IQS requirements, test targets, test procedures, acceptability of alternate targets/procedures, certification procedures, or availability of test analysis software (Test Tools CD), can be addressed to mtf@mitre.org, which acts on the FBI's behalf for purposes of IQS testing.

Questions and concerns may also be addressed to Eric Phillips of the FBI:

Eric M. Phillips

Telephone: 304-625-4531
Email: eric.phillips@ic.fbi.gov

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SECTION 2

FINGERPRINT SCANNER

2.1 LINEARITY

2.1.1 Requirements

When measuring a stepped series of uniform target reflectance patches ("step tablet") that substantially cover the scanner's gray range, the average value of each patch shall be within 7.65 gray-levels of a linear, least squares regression line fitted between target reflectance patch values (independent variable) and scanner output gray-levels (dependent variable).

2.1.2 Background

All targets used in IQS compliance verification are expected to be scanned with the scanner operating in a linear input/output mode. Linearity enables valid comparisons of test measurements with requirements; e.g., a system's spatial frequency response in terms of Modulation Transfer Function is, strictly speaking, a linear systems concept. Linearity also facilitates comparisons between different scanners through the "common ground" concept. For fingerprint scans, linearity produces a pristine image in a common reference base. From this base, users such as an Automated Fingerprint Identification System (AFIS) or fingerprint examiners working in softcopy, can then apply linear/non-linear processing, as needed for specific purposes, with the benefit that they are always able to get back to the base image.

However, in atypical cases, linearity may be waived for test target scans; i.e., a small amount of smooth, monotonic nonlinearity may be acceptable when it is substantially impractical and unrepresentative of operational use to force linearity on the scanner under test. Such cases require the submission of documentation along with the waiver request.

It is recognized that the ten-print card, latent photo, or live finger input to the scanner may have less than ideal characteristics, in terms of average reflectance, discontinuities in average reflectance, low contrast, and/or background clutter. Such problems may sometimes be minimized by applying nonlinear gray-level processing to the scanner-captured image. For example, reduction of white background clutter surrounding a fingerprint leads to more of the available image compression bits being allocated to the fingerprint itself, which results in higher quality when the fingerprint image is decompressed. For these reasons, linearity is not a requirement for the operational or test fingerprint scans.

2.1.3 Target

For a paper scanner, or any live scanner that can image a continuous tone target, a step tablet covering the dynamic range of the scanner shall be used as the target; e.g., the step tablet component of the sine wave target used for MTF assessment fulfills this purpose (see Figure 2-7).

For live scanners that cannot image a continuous tone target, the appropriate target is dependent on the live scanner's design and imaging capabilities. For example, it may be necessary to produce a series of images of neutral density filters inserted into the optical path, or a series of images of a uniform (blank) platen with variation of exposure time at constant intensity. Whatever target/method is used, it must produce at least 9 unique gray-level steps covering the dynamic range of the scanner.

See Appendix B for commercial sources for step tablets.

2.1.4 Test Procedures

A linear, least squares regression is run between the step-averaged target reflectance or transmission values (input predictor variable), and the corresponding step-averaged scanner output gray-levels (output response variable), producing the equation of a straight line:

$$\text{Predicted OutputGrayLevel} = \text{Slope} \times \text{TargetReflectance} + \text{Intercept}$$

The deviation of each step-averaged scanner output step gray-level from the linear, least squares regression line of best fit is noted, as illustrated in Figure 2-1.

The linearity requirement can be verified with the *sinemtf* software, which is on the IQS Test Tools CD. The latest version of *sinemtf* is always posted to the internet at:

http://www.mitre.org/tech/mtf

2.1.5 Requirements Compliance

For each of the target steps, the absolute value of the difference between the step-averaged scanner output gray-level and the linear regression predicted gray-level, shall be no greater than 7.65 gray-levels.

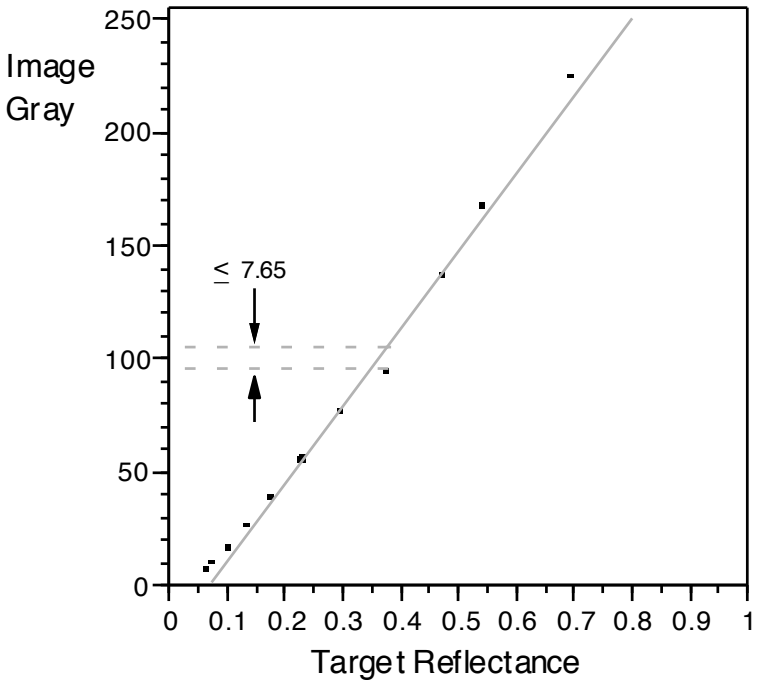

Figure 2-1. Linearity Requirement for Scanner Input/Output

2.2 RESOLUTION AND GEOMETRIC ACCURACY

2.2.1 Requirements

Resolution:
The scanner's final output fingerprint image shall have a resolution, in both sensor detector row and column directions, in the range: (R – 0.01R) to (R + 0.01R). The magnitude of "R" is either 500 ppi or 1000 ppi; a scanner may be certified at either one, or both, of these resolution levels. The scanner's true optical resolution shall be greater than or equal to R.

Across-Bar Geometric Accuracy:
When scanning a 1.0 cy/mm, multiple parallel bar target, in both vertical bar and horizontal bar orientations, the absolute value of the difference (D), between the actual distance across parallel target bars (X), and the corresponding distance measured in the image (Y), shall not exceed the following values, for at least 99% of the tested cases in each printblock measurement area and in each of the two directions.

for 500 ppi scanner:

$D \leq 0.0007$, for $0.00 < X \leq 0.07$

$D \leq 0.01X$, for $0.07 \leq X \leq 1.50$

for 1000 ppi scanner:

$D \leq 0.0005$, for $0.00 < X \leq 0.07$

$D \leq 0.0071X$, for $0.07 \leq X \leq 1.50$

where:

$D = |Y-X|$
X = actual target distance
Y = measured image distance
D, X, Y are in inches

Along-Bar Geometric Accuracy:
When scanning a 1.0 cy/mm, multiple parallel bar target, in both vertical bar and horizontal bar orientations, the maximum difference in the horizontal or vertical direction, respectively, between the locations of any two points within a 1.5 inch segment of a given bar image, shall be less than 0.016 inches for at least 99% of the tested cases in each printblock measurement area and in each of the two orthogonal directions.

2.2.2 Background

A *multiple parallel bar target* refers to a Ronchi target, which consists of an equal-width bar and space square wave pattern with high contrast ratio and sharp edge definition.

For a 500 ppi system, the resolution must be between 495.0 and 505.0 ppi; for a 1000 ppi system, the resolution must be between 990.0 and 1010.0 ppi. The scanner's true optical resolution may be greater than the required resolution, in which case rescaling down to the required resolution is performed for final output. However, the scanner's true optical resolution cannot be less than the required resolution; i.e. "upscaling", from less than the required ppi resolution, to the required ppi resolution, is not allowed.

Across-bar geometric accuracy is measured across imaged 1.0 cy/mm Ronchi target bars that substantially cover the total image capture area. The 500 ppi requirement corresponds to a positional accuracy of ± 1.0% for distances between 0.07 and 1.5 inches, and a constant ± 0.0007 inches (1/3 pixel) for distances less than or equal to 0.07 inches. The 1000 ppi requirement corresponds to a positional accuracy of ± 0.71% for distances between 0.07 and 1.5 inches, and a constant ± 0.0005 inches (1/2 pixel) for distances less than or equal to 0.07 inches.

Along-bar geometric accuracy is measured along the length of imaged, 1.0 cy/mm Ronchi target bars that substantially cover the total image capture area. For a given horizontal bar, for example, the maximum difference between bar center locations (in vertical direction), determined from bar locations measured at multiple points along a 1.5 inch bar segment length, is compared to the maximum allowable difference requirement (analogously for vertical bar). This requirement is to ensure that pincushion or barrel distortion over the primary area of interest; i.e., a single fingerprint, is not too large.

2.2.3 Target

Scanner resolution and geometric accuracy are measured using a precision Ronchi target having a constant spatial frequency of 1.0 cy/mm; i.e., the combined width of one black bar plus one adjacent white space is 1.0 mm, which is one cycle, or one period. This target is available on a reflective white mylar substrate, which is suitable for use in testing paper scanners. Live scanners may require use of a different substrate, such as a chrome-on-glass Ronchi target. Ronchi targets on mylar and glass substrates are commercially available from several vendors – see Appendix B.

For a card scanner, testing shall be performed over a 4 x 8 inch area, in both vertical and horizontal directions. The required two positions and two orientations of a typically available 4 x 4 inch Ronchi target are illustrated in Figure 2-2. The preferred method is to mount two 4 x 4 inch Ronchi targets on a single ten-print card stock, then, only two scans are required, with the card rotated 180 degrees for the second scan. Alternatively, a single 4 x 4 inch Ronchi target can be alternately placed in the two locations and two orientations, but this requires four separate scans and does not capture both directions in a single scan.

The Scanner Image Quality Test (SIQT) target was designed for testing fingerprint card scanners. If this target is included in the FBI supplied ten-print test card set (see section 2.6), or is otherwise available, then it should also be scanned on the card scanner. This target contains horizontal and vertical Ronchi bars and serves as a good adjunct measurement of geometric accuracy, particularly useful when marginal results are obtained with the required 4 x 4 inch Ronchi targets. See Appendix B for commercial sources for the SIQT target.

For a live scanner, resolution and geometric accuracy testing shall be performed over at least 70% of the scanner's capture area, in both vertical and horizontal directions.

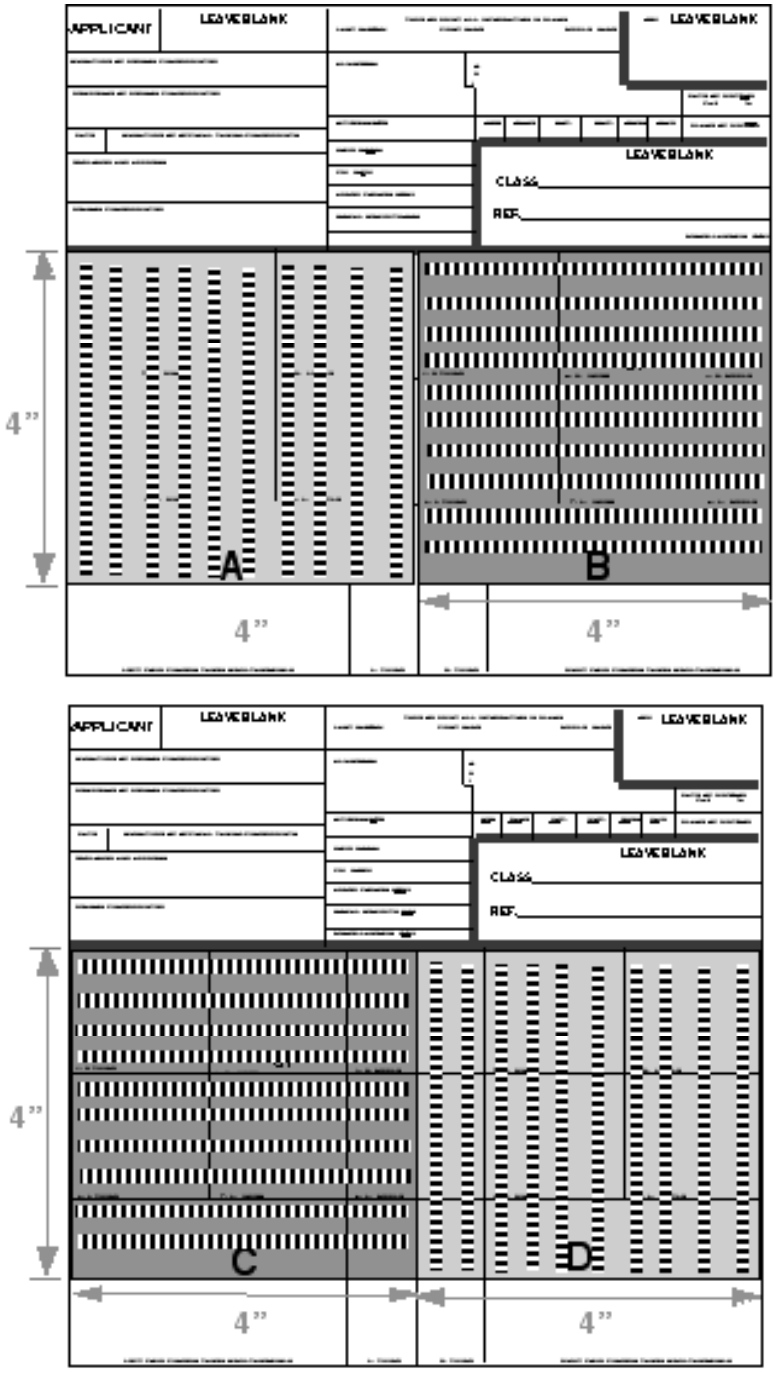

Figure 2-2. Layout of Four 4 x 4 Inch Ronchi Targets (A & D - Horizontal Bars, B & C - Vertical Bars, nominal number of 10 measurement strips per target)

2.2.4 Test Procedures

2.2.4.1 Resolution and Across-Bar Geometric Accuracy

The goal is to acquire measurements that comprehensively cover a Ronchi target image, in continuous, 1/4 inch wide measurement strips running the height (vertical direction measurements) or width (horizontal direction measurements) of the target image. Target blemishes or dust may negate successful measurement in isolated areas; in such cases it may be necessary to segment a long, single measurement strip depicted in Figure 2-2 into a number of shorter strips, or shift measurement locations.

For each measurement strip, measurements are taken across all independent one bar distances and six bar distances. First, the scanner output resolution is measured over 6 Ronchi bar cycles ("6-bar distance"); this verifies compliance with the pixels per inch requirement and establishes a pixels per inch value that can be used to convert subsequent geometric accuracy measurements to inches. Next, measurements are made to test the geometric accuracy over a short distance of one Ronchi bar cycle ("1-bar distance"). Finally, measurements are made to test the geometric accuracy over a longer distance of 6 Ronchi bar cycles. All distances for geometric accuracy are measured from bar center to bar center in pixel units, as illustrated in Figure 2-3. The pixel measurements are then converted to inches using the previously computed average resolution for the given measurement strip. A bar center is located by first detecting that bar's left and right edges along a 1/4 inch edge height (for vertical bar in scanner assessment), and then bisecting the bar's two edges, taking skew angle into account.

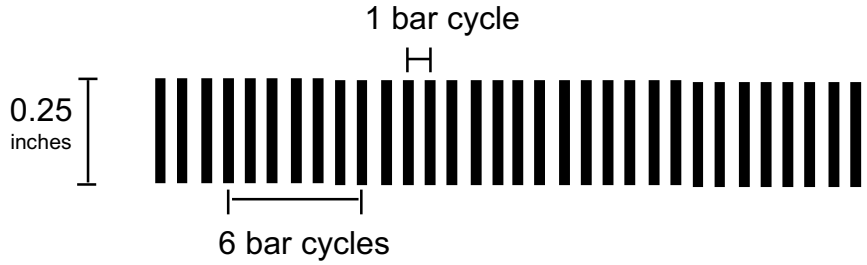

Figure 2-3. Bar Center to Bar Center Measurements

2.2.4.2 Along-Bar Geometric Accuracy

This test for distortion utilizes the same Ronchi targets used for across-bar geometric accuracy assessment. All distances for along-bar geometric accuracy are first measured from local bar center location to local bar center location in pixel units. The difference in

fractional rows between two bar centers is converted to inches by dividing by the average ppi of the two corresponding measurement strips. Figure 2-4 illustrates a single measurement for a single horizontal bar. In this example, the maximum vertical deviation "H" occurs for two bar center locations that are spaced at the maximum measurement distance of 1.5 inches (in horizontal direction), but note that the maximum vertical deviation could occur at bar center locations that are less than 1.5 inches apart.

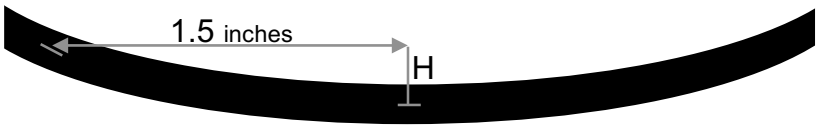

Figure 2-4. Along-Bar Geometric Accuracy Assessment (Vertical Height "H" is Test Sample Value)

The geometric accuracy and resolution requirements can be verified with the *geo* software, supported by *createfeofile* and *viewgeo* software, which are on the IQS Test Tools CD. See Appendix C for a detailed description of the computations performed in *geo*.

2.2.5 Requirements Compliance

The resolution requirement is complied with if the average resolution, in each printblock measurement area, and in each direction, is within 1.0 percent of the required scanner resolution, as delineated in Table 2-1.

The across-bar geometric accuracy requirement is complied with if at least 99.0 percent of the tested cases, in each printblock measurement area, and in each direction, are within the minimum and maximum distance limits defined in Table 2-1.

The along-bar geometric accuracy requirement is complied with if at least 99.0 percent of the test measurement values ("H" in Figure 2-4), in each printblock measurement area and in each direction, are less than 0.016 inches.

Table 2-1. Geometric Accuracy (inches) and Resolution (ppi) Requirements

Measurement	Correct Value	Directional Requirement Met if:
1-bar distance @ 500 ppi	0.03937	≥ 99% in range: 0.03867 to 0.04007
1-bar distance @ 1000 ppi	0.03937	≥ 99% in range: 0.03887 to 0.03987
6-bar distance @ 500 ppi	0.23622	≥ 99% in range: 0.23386 to 0.23858
6-bar distance @ 1000 ppi	0.23622	≥ 99% in range: 0.23454 to 0.23790
500 ppi resolution	500.0	avg in range: 495.0 to 505.0
1000 ppi resolution	1000.0	avg in range: 990.0 to 1010.0

2.3 SPATIAL FREQUENCY RESPONSE

2.3.1 Requirements

The spatial frequency response shall be measured using a continuous tone sine wave target, denoted as Modulation Transfer Function (MTF) measurement, unless the scanner cannot obtain adequate tonal response from this target, in which case a bi-tonal bar target shall be used to measure the spatial frequency response, denoted as Contrast Transfer Function (CTF) measurement. When measuring the sine wave MTF, it shall meet or exceed the minimum modulation values given in Table 2-2, in both the detector row and detector column directions, and over any region of the scanner's field of view. When measuring the bar CTF, it shall meet or exceed the minimum modulation values defined by equation 2-1 or equation 2-2 (whichever applies), in both the detector row and detector column directions, and over any region of the scanner's field of view. CTF values computed from equations 2-1 and 2-2 for nominal test frequencies are given in Table 2-3. The specification MTFs and CTFs are plotted in Figure 2-5.

None of the MTF or CTF modulation values measured at specification spatial frequencies shall exceed 1.05.

The output sine wave image or bar target image shall not exhibit any significant amount of aliasing.

Table 2-2. MTF Requirement Using Sine Wave Target

Frequency (cy/mm)	Minimum Modulation for 500 ppi Scanner	Minimum Modulation for 1000 ppi Scanner	Maximum Modulation
1.0	0.905	0.925	1.05 at all frequencies
2.0	0.797	0.856	
3.0	0.694	0.791	
4.0	0.598	0.732	
5.0	0.513	0.677	
6.0	0.437	0.626	
7.0	0.371	0.579	
8.0	0.312	0.536	
9.0	0.255	0.495	
10.0	0.200	0.458	
12.0		0.392	
14.0		0.336	
16.0		0.287	
18.0		0.246	
20.0		0.210	

Note: Testing at 7 and 9 cy/mm is not a requirement if these frequency patterns are absent from the sine wave target.

Table 2-3. CTF Requirement Using Bar Target (Nominal Test Frequencies)

Frequency (cy/mm)	Minimum Modulation for 500 ppi Scanner	Minimum Modulation for 1000 ppi Scanner	Maximum Modulation
1.0	0.948	0.957	1.05 at all frequencies
2.0	0.869	0.904	
3.0	0.791	0.854	
4.0	0.713	0.805	
5.0	0.636	0.760	
6.0	0.559	0.716	
7.0	0.483	0.675	
8.0	0.408	0.636	
9.0	0.333	0.598	
10.0	0.259	0.563	
12.0		0.497	
14.0		0.437	
16.0		0.382	
18.0		0.332	
20.0		0.284	

Note: Testing at or near 7 and 9 cy/mm is a requirement when using a bar target.

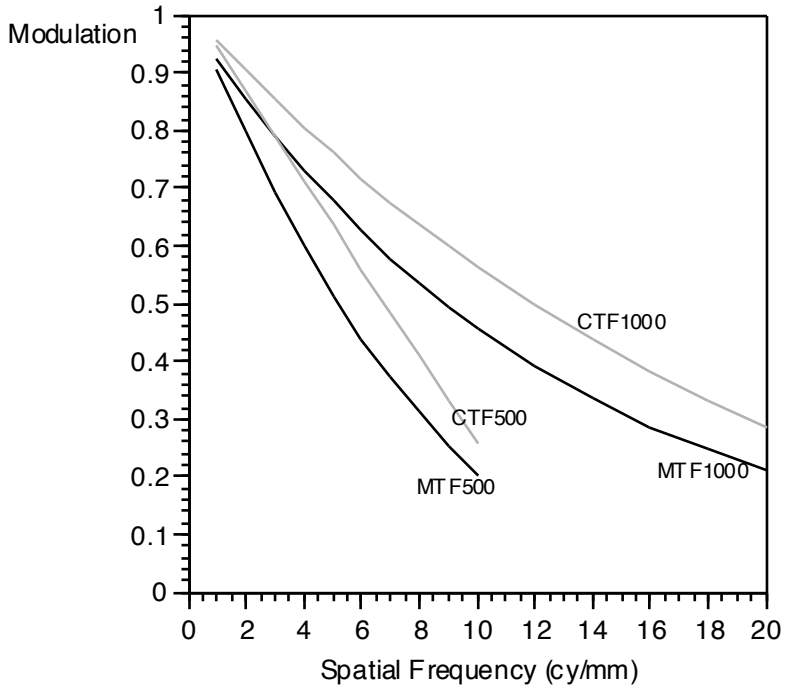

Figure 2-5. Specification Scanner MTFs (Sine Wave Target) and CTFs (Bar Target)

It is not required that the bar target contain the exact frequencies listed in Table 2-3; however, the target does need to cover the listed frequency range and contain bar patterns close to each of the listed frequencies. The following equations are used to obtain the minimum acceptable CTF modulation values when using bar targets that contain frequencies not listed in Table 2-3.

500 ppi scanner, for f = 1.0 to 10.0 cy/mm:
$CTF = 3.04105E\text{-}04*f^2 - 7.99095E\text{-}02*f + 1.02774$ (2-1)

1000 ppi scanner, for f = 1.0 to 20.0 cy/mm:
$CTF = -1.85487E\text{-}05*f^3 + 1.41666E\text{-}03*f^2 - 5.73701E\text{-}02*f + 1.01341$ (2-2)

For a given bar target, the specification frequencies include all of the bar frequencies which that target has in the range 1 to 10 cy/mm (500 ppi scanner) or 1 to 20 cy/mm (1000 ppi scanner).

2.3.2 Target

For a paper scanner, a commercially available, reflective sine wave target is used (this target can also be used to verify the linearity requirement in section 2.1).

For a live scanner, it may be possible to use a reflective or transmissive sine wave target, and this is the first choice. If the live scanner is not compatible with capturing a sine wave target and producing a continuous gray tone image, then a bi-tonal, black & white, bar target is used. The bar target must have the following properties:

- Bars must cover the frequency range from 1 cy/mm up to the scanner output Nyquist frequency of 10 cy/mm for a 500 ppi scanner, or 20 cy/mm for a 1000 ppi scanner. The bar target frequency patterns must be within 0.49 cy/mm of each of the frequency increments: 1, 2, 3, 4, 5, 6, 7, 8, 9 cy/mm, and within 0.25 cy/mm of 10 cy/mm.

- The bar target must contain at least one very low frequency component; i.e., a large square, single bar, or series of bars whose effective frequency is no greater than 3% of the scanner output Nyquist frequency. This low frequency component is used in normalizing the CTF; it must have the same density on the target as the other target bars. For example, a scanner with 500 ppi output resolution would require that the target contain at least one bar whose width is at least 1.7 mm.

- In the frequency range of 1 cy/mm up to the scanner output Nyquist frequency, there must be an adequate number of target bars at each frequency; a minimum number is defined in Table 2-4. A minimum number of bars is needed in order to ensure capturing the optimum phase between scanner sensor array and target bars, in order to have enough samples available for accurate measurement of aliasing, and in order to obtain an accurate measure of modulation.

Table 2-4. Minimum Number of Target Bars

Target Frequency	Minimum Number of Parallel Bars
≤ 3% of Nyquist	1
> 3% of Nyquist to 1 cy/mm	4
> 1 to 4 cy/mm	5
> 4 cy/mm	10

Notes: Bar length must be at least 5 times bar width.
Width of space between parallel bars equals bar width.

- The bar target may be either a commercially purchased standard bar target design (see Appendix B), or may be specially designed/fabricated for the IQS testing. The bar target may have any suitable substrate (paper, mylar, film, glass), depending on the imaging requirements of the specific live scanner. Bar targets seldom include a step tablet; the linearity requirement must therefore be tested with other test targets and other methods, as appropriate for the particular live scanner design.

2.3.3 Test Procedures

1) The acceptable number of locations and orientations of a target depends principally on target size, relative to the scanner's total capture area, and whether or not the target contains frequency patterns in one direction, or in two orthogonal directions. In every case, however, the target must be oriented such that the scanner's spatial frequency response can be measured in both horizontal and vertical directions (scanner detector array row and column directions). The following subsections 2.3.3(a), 2.3.3(b) and 2.3.3(c) present guidelines for acceptable layouts for some common target designs, as summarized in Table 2-5. Other target designs or potentially unique aspects of image capture areas may require other layouts.

a) If the area of the target is less than 25% of the scanner's total capture area, then an acceptable layout consists of one vertical and one horizontal target, each located off-center. Example layouts are illustrated in Figure 2-6 for bar targets in an Identification Flats live scanner, and in Figure 2-7 for 2 x 3 inch sine wave targets in a ten-print card scanner.

b) If the area of the target is greater than or equal to 25% of the scanner's total capture area, then an acceptable layout consists of one target centered in the image capture area, capturing both vertical and horizontal bar orientations (via separate scans, if necessary). Figure 2-8 is an example layout of a single bar target with both vertical and horizontal components in a roll capture area.

c) If the scanner has a large total capture area (such as half-palm or Identification Flats) with a small subsection devoted to roll captures, then the target must be imaged in the critical roll capture area (via separate scans, if necessary) as well as across the full capture area as required in 2.3.3(a) or 2.3.3(b).

Table 2-5. Minimum Target Layouts

Target Area as % of Total Capture Area	Target Contains Vertical (V) and Horizontal (H) Components	Target Contains Vertical (V) or Horizontal (H) Components
< 25%	Single scan of two off-center targets; or separate scan of each of two off-center targets	Single scan of two off-center targets, one V target & one H target; or separate scans of one off-center V target and one off-center H target
≥ 25%	Single scan of centered target	Separate scans of one centered V target and one centered H target

Notes:

- The target area is the area of the target itself; e.g., area covered by sine patterns and surrounding gray patches, or the area of an array of bars, regardless of the target substrate dimensions.
- "Centered target" means that the center of the target coincides with the point at which the scanner's optical axis intersects the scanner's object plane, which usually coincides with the center of the capture area.
- When two off-center targets are used, they are expected to be on opposite sides of the center of the capture area.

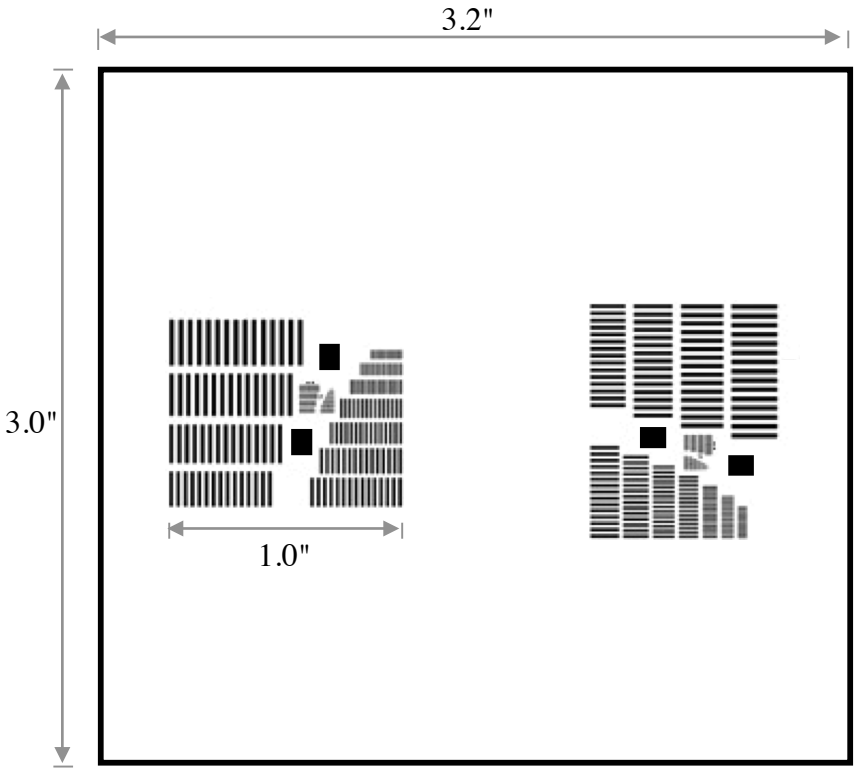

Figure 2-6. Example Layout for 15-Bar Target in Identification Flats Live Scanner (Single Target Area is 10% of Capture Area)

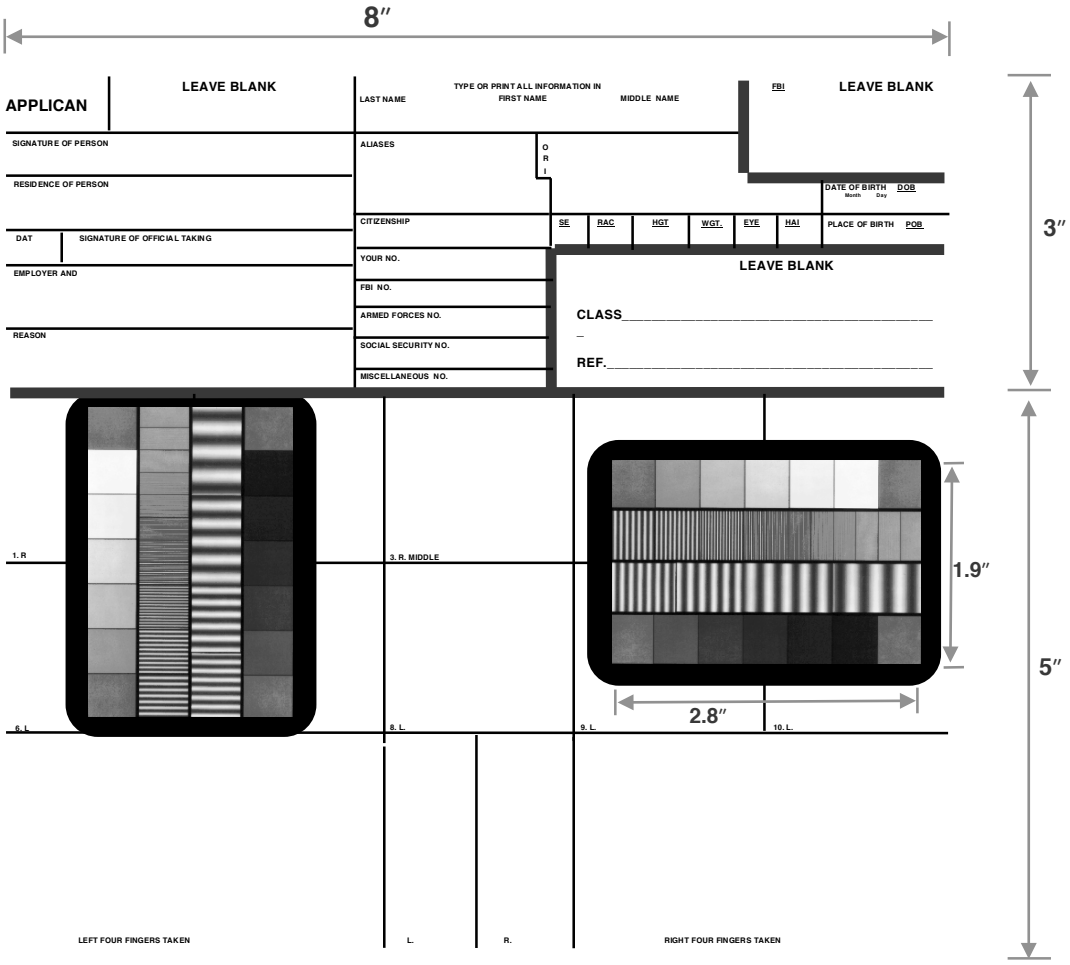

Figure 2-7. Example Layout for 2 x 3 Inch Sine Wave Target (M13-60-1X) in Card Scanner (Single Target Area is 8% of Capture Area)

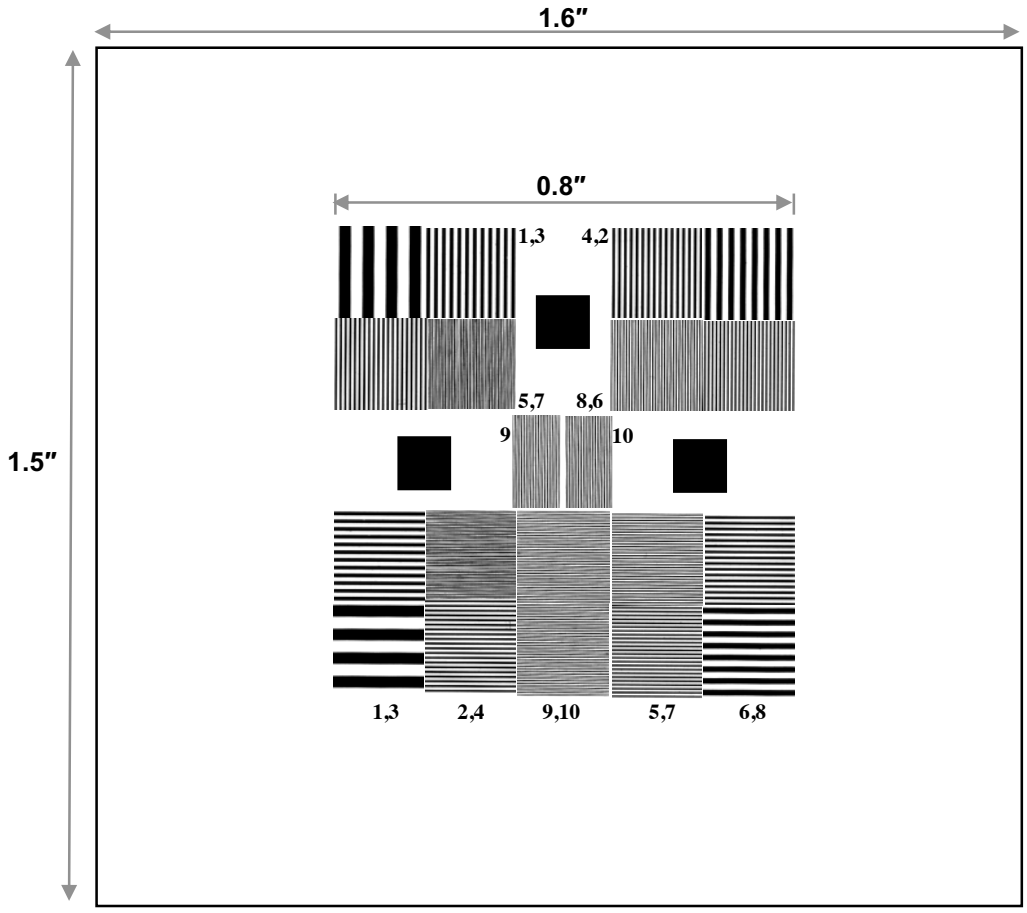

Figure 2-8. Example Layout for Bi-Directional Bar Target Centered in Roll Capture Area (Target Area is 27% of Roll Capture Area)

The following procedures, sections 2.3.3(2) to 2.3.3(7), correspond to input requirements and computations performed by the *sinemtf* software for MTF and CTF assessment. This software, together with detailed documentation, can be found on the IQS Test Tools CD; the most recent version of *sinemtf* can also be downloaded from the internet at:

http://www.mitre.org/tech/mtf

2) A target data file is prepared for each target model, which includes the relative locations within the target of each frequency pattern, the modulation value of each frequency pattern, and gray patch densities/locations (if target contains gray patches).

For a sine wave target, the target manufacturer supplies the target modulations and gray patch densities for the specific target serial number purchased. The supplied "compensated modulation" values are used for target modulation, because these values have been corrected for the instrument (microdensitometer) used by the manufacturer to calibrate the target. [The supplied "peak-to-peak" modulation is not used, because these values have not been corrected.] The constructed target data file is submitted along with the target scans. As verification that "compensated modulation" has been used, at least a portion of the target manufacturer's data sheet for the specific serial-numbered sine wave target should also be submitted; e.g., the portion which includes target modulation data at 6 cy/mm.

3) The target is positioned on the scanner platen, aligned to within 0.5 degrees of the horizontal and vertical (scanner detector array rows and columns), and scan capture parameters are appropriately set. Note that due to the medium contrast of sine wave targets it is relatively easy to avoid saturation upon imaging; i.e., easy to avoid the sine wave peaks in the image being pinned at gray = 255 or the sine wave valleys being pinned at gray = 0. On the other hand, a bar target is very high contrast and is more prone to producing a saturated image. Adjustments in scanner parameters (illumination, gain settings, etc.) should be made, as necessary to avoid saturation. If some bar target saturation is unavoidable, it is better to saturate the white spaces at gray = 255 rather than the black bars at gray = 0.

4) The target is scanned. For any case in which more than one target is captured in a single scan, the single scan should be submitted, not cropped or segmented into separate target images.

5) The digital image of the scanned target is displayed and the upper left, upper right, and lower left corners are located (row and column in pixel units). *Sinemtf* is then run, with inputs consisting of the 3 image reference corners, target data file, digital image, and various user-selectable options displayed at runtime. *Sinemtf* first computes the pixels per inch and alignment angle ("skew angle") in both vertical and horizontal directions for the given target image. This data, together with the relative locations of each target

pattern (from input data file), is then used to establish the row and column location of each density patch and each sine wave (or bar) frequency pattern within the image.

6) The single, representative sine wave (or bar cycle) modulation in each imaged frequency pattern is determined from the sample modulation values collected from within that pattern. The sample modulation values are computed from the maximum and minimum levels corresponding to the peak and adjacent valley in each sine wave period (or bar cycle). These maximum and minimum levels represent the image gray-levels that have been locally averaged in a direction perpendicular to the sinusoidal (or bar cycle) variation; for sine waves, these maximum and minimum gray-levels are then mapped through a calibration curve into target reflectance space where the image modulation is computed as,

peak_image_modulation = (maximum - minimum) / (maximum + minimum)

The calibration curve is the curve of best fit between the image gray-levels of the density patches in the sine wave target and the corresponding target reflectance values. The scanner MTF at each frequency is then defined as:

MTF = peak_image_modulation / target_modulation

For CTF assessment using a bar target, the modulations are determined in image space, normalized by the image modulation at zero frequency[6], instead of using a calibration curve. The scanner CTF at each frequency is then defined as:

CTF = peak_image_modulation / zero_frequency_image_modulation

[Unless specifically measured, a bar target's modulation values are assumed to be constant, at all frequencies up to the scanner output Nyquist frequency.]

A maximum modulation of 1.05 is defined to discourage the use of sharpening, edge enhancement, or MTF-boost filters in the signal processing that produces the image; these filters tend to make the MTF go above 1.0 at some frequencies. These filters are unwanted for two reasons: (1) they have the potential for introducing artifacts that are not in the original fingerprint; i.e., a pristine digitized fingerprint is desired, and (2) they can introduce high frequency energy which prevents the creation of the smooth edge surfaces that are compatible with wavelet compression techniques (WSQ, JPEG-2000).

[6] In this context, "zero frequency" refers to any single or multiple bar pattern whose spatial frequency is no greater than 3% of the scanner output Nyquist frequency.

7) Aliasing Measurement - Aliasing is measured because it is a potential source of unwanted image artifacts; e.g., pronounced aliasing may produce false detail in the image, such as a pseudo-ridge pattern. Aliasing is measured in *sinemtf* by computing a sequence of one-dimensional discrete Fourier transforms (DFT) of the row-averaged gray-levels in each frequency pattern. If the relative strengths of side lobes (harmonics) compared to the main lobe are too large, then aliasing due to nonuniform decimation is called out. If the location of the main lobe is not at the correct frequency, for a given pattern with known fundamental frequency, then aliasing due to upscaling is called out. Aliasing due to decimation is usually not entirely avoidable when the scanner's true optical resolution is greater than the required 500 ppi or 1000 ppi, because of the rescaling algorithm (resampling and interpolation) that must be applied in order to reduce the optical resolution to the required final output resolution. However, there is ample empirical evidence which indicates that decimation aliasing at/near the Nyquist frequency can be substantially avoided with the correct algorithm, while maintaining sharpness and detail rendition. On the other hand, aliasing due to upscaling is not acceptable at any frequency up to and including the Nyquist frequency, because it implies that the true optical resolution is lower than the required 500 ppi or 1000 ppi. More details of this quantitative alias detection technique can be found in the MTF document[7] which is on the IQS Test Tools CD.

The DFT-based, quantitative assessment of aliasing is dependent on the threshold levels chosen, which have been judiciously chosen in *sinemtf*, based on experimentation. It is useful, however, to apply other alias detection techniques, in order to obtain as complete a picture of aliasing as is possible. As it happens, one of the benefits of a sine wave target (or bar target) is that it readily lends itself to showing the effects of aliasing at specific frequencies; e.g., visible banding is one tell-tale sign of aliasing; for more detail, see illustrations in the Rescale document[8] which is on the IQS Test Tools CD. A more comprehensive assessment of the magnitude and potential impact of aliasing is therefore achieved by the synergistic combination of the quantitative, DFT approach and the qualitative, visual assessment approach.

2.3.4 Requirements Compliance

1) The MTF, if applicable, shall meet the minimum modulation requirements given in Table 2-2. The CTF, if applicable, shall meet the minimum modulation requirements as defined in equation 2-1 or equation 2-2 (whichever applies). The MTF or CTF modulation requirements shall be met for both vertical and horizontal target pattern orientations, and for the target locations as described in Section 2.3.3.

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[7] "Computer Program to Determine the Sine Wave MTF of Imaging Devices", N.B.Nill, D.J.Braunegg, B.R.Paine, MITRE Corp. Technical Report, MTR-96B025, June 1996; Section 2.8, "Detection of Aliasing"

[8] "Rescaling Digital Fingerprints: Techniques and Image Quality Effects", D.J.Braunegg, R.D.Forkert, N.B.Nill, MITRE Corp. Technical Report, MTR-95B061, June 1995.

2) None of the MTF or CTF modulation values measured at specification spatial frequencies shall exceed 1.05.

3) When applying a suitable quantitative alias detection metric, supported by visual observation, the aliasing requirement is met when no substantial aliasing-due-to-decimation is detected at any frequency less than 70% of the required output resolution, and no aliasing-due-to-upscaling is detected at any frequency less than or equal to the required output resolution.

2.4 SIGNAL TO NOISE RATIO TEST

2.4.1 Requirements

The white signal-to-noise ratio and black signal-to-noise ratio shall each be greater than or equal to 125.0, in at least 97% of respective cases, within each printblock measurement area.

2.4.2 Background

The signal is defined as the difference between the average output gray-levels obtained from scans of a uniform low reflectance and a uniform high reflectance target, measuring the average values over independent 0.25 by 0.25 inch areas ("quarter-inch areas") within each printblock area. The noise is defined as the standard deviation of the gray-levels in each quarter-inch measurement area. Therefore, for each high reflectance, low reflectance quarter-inch image pair, there are two SNR values, one using the high reflectance standard deviation and one using the low reflectance standard deviation. The scanner must be set up such that the average image gray-level of the high reflectance target is below 255 or high clipping level, whichever is lower, and the average image gray-level of the low reflectance target is above 0 or low clipping level, whichever is higher. Note that in this method of measuring SNR, no attempt is made to isolate different sources of noise or separately measure different types of noise; the computed noise represents all noise types and sources taken together.

2.4.3 Target

For a paper scanner, two uniform, neutral gray targets with matte reflectance on paper or mylar base are used. One target has high reflectance, denoted as the white target, such as Munsell model N9 (79% reflectance). The other target has low reflectance, denoted as the black target, such as Munsell model N3 (7% reflectance). [See Appendix B for target manufacturers.]

For a card scanner, the white and black targets can be mounted together, covering a 5 x 8 inch area of a single, 8 x 8 inch card stock, as depicted in Figure 2-9. Alternatively, the

white and black targets can be mounted on separate 8 x 8 inch card stocks, each covering a 5 x 8 inch measurement area.

For live scanner testing a different target substrate may be required; e.g., flashed photographic emulsion on mylar base. Alternatively, it may be necessary to separately capture equivalent white and black images with a blank livescan platen (no actual target), such as by inserting a neutral density filter in the optical path or by adjusting the detector integration time. In either case, the target or pseudo-target should cover the entire livescan image capture area.

Note that the input/output linearity established for the test environment needs to extend to these white and black target reflectance values.

2.4.4 Test Procedures

1) The scanner is adjusted so that the average output gray-level of the white target is at least 4.0 gray-levels below the maximum gray-level, and the average output gray-level of the black target is at least 4.0 gray-levels above the minimum gray-level. For a system that captures/outputs the full 8 bpp, 256 gray-level range, the maximum and minimum gray-levels are 255 and 0, respectively, in which case the white average must be less than or equal to 251.0 and the black average must be greater than or equal to 4.0. However, if the scanner system is setup such that some gray-levels cannot occur, then the maximum or minimum value must be adjusted accordingly. For example, if gray-levels 253, 254, 255 cannot occur because they are always clipped-out of an image (for whatever reason), then the maximum gray-level would be 252 and the white average would need to be less than or equal to 248.0.

2) If using the composite target illustrated in Figure 2-9, then the composite target is scanned, rotated 180 degrees, and scanned again. If using separate black and white targets, each target is scanned. In either approach, the two images result in both a white and black image segment on both the left and right sides of the total image area.

3) The locations of all independent quarter-inch windows that fit within each printblock area are identified. For a card scanner this produces 6 rows and 6 columns of quarter-inch windows for each rollblock, for a total of 36 windows per rollblock, 21 windows for each plain thumb block, and 84 windows for each 4-finger plain block. For a live scanner, all independent quarter-inch windows that fit within the capture area are identified.

4) The average, $\bar{x}$, and the standard deviation, σ, for each of the quarter-inch windows in the white and black target scans are computed. The SNR value for each quarter-inch

black/white window pair[9] is then computed using σ_{white} and σ_{black}, according to the formulas:

$$SNR_{white} = \left\lceil \frac{\bar{x}_{white} - \bar{x}_{black}}{\sigma_{white}} \right\rceil$$

$$SNR_{black} = \left\lceil \frac{\bar{x}_{white} - \bar{x}_{black}}{\sigma_{black}} \right\rceil$$

5) Notes:

- The SNR requirement can be verified with the *snr* software, which is on the IQS Test Tools CD. [*Snr* avoids the area around the white/black target join line shown in Figure 2-9.]

- If, after careful cleaning of the target and scanner platen, a small quantity of measurement samples still contain residual artifacts, such as dust, pinholes, scratches, or smudges on the target, then these samples may be discounted from the final test sample size.

2.4.5 Requirements Compliance

The requirement is complied with if SNR_{white} and SNR_{black} are each greater than or equal to 125 in at least 97 percent of the respective cases, in each of the fourteen print blocks for a card scanner, and over the total image capture area for a live scanner.

[9] A "window pair" is a quarter-inch black window and quarter-inch white window, alternately occupying the same location in the total capture area.

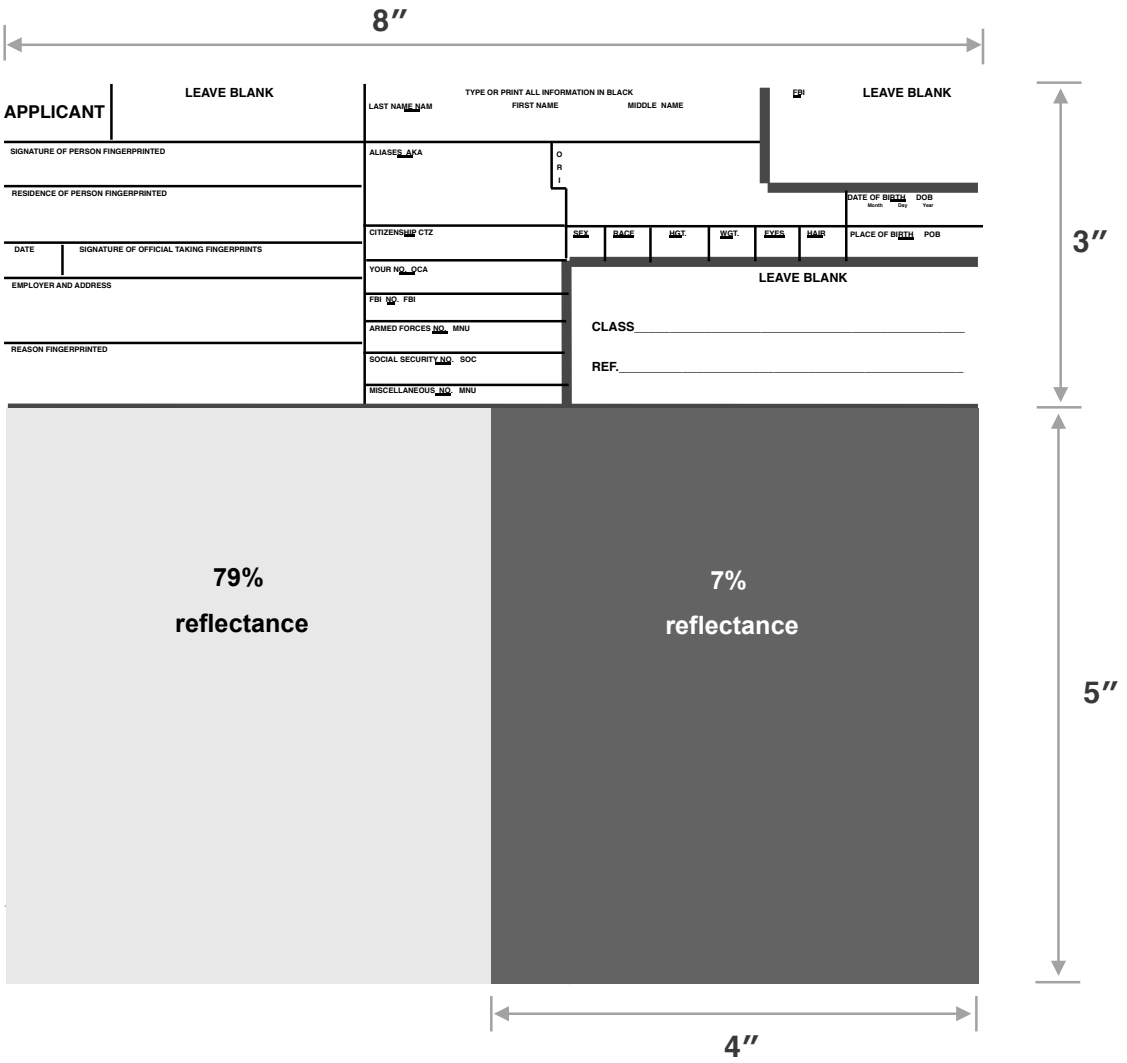

Figure 2-9. Composite of Two Uniform Gray Targets

2.5 GRAY-LEVEL UNIFORMITY

2.5.1 Requirements

#1 - Adjacent Row, Column Uniformity:
At least 99% of the average gray-levels between every two adjacent quarter-inch long rows and 99% between every two adjacent quarter-inch long columns, within each imaged printblock area, shall not differ by more than 1.0 gray-levels when scanning a uniform low reflectance target, and shall not differ by more than 2.0 gray-levels when scanning a uniform high reflectance target.

#2 - Pixel to Pixel Uniformity:
For at least 99.9% of all pixels within every independent 0.25 by 0.25 inch area located within each imaged printblock area, no individual pixel's gray-level shall vary from the average by more than 22.0 gray-levels, when scanning a uniform high reflectance target, and shall not vary from the average by more than 8.0 gray-levels, when scanning a uniform low reflectance target.

#3 - Small Area Uniformity:
For every two independent 0.25 by 0.25 inch areas located within each imaged printblock area, the average gray-levels of the two areas shall not differ by more than 12.0 gray-levels when scanning a uniform high reflectance target, and shall not differ by more than 3.0 gray-levels when scanning a uniform low reflectance target.

2.5.2 Target

The targets are the same as used for SNR assessment, see Section 2.4.3.

2.5.3 Test Procedures

2.5.3.1 Preparation

The target scans are the same scans used in SNR assessment, see Section 2.4.4.

2.5.3.2 Adjacent Row, Column Uniformity Test Procedure

For each of the fourteen print block areas of the white target and black target, the average pixel values of individual 0.25 inch long horizontal row segments and individual 0.25 inch long vertical column segments are computed (avoiding column or row segments near the black/white target join line shown in Figure 2-9). For a given image (black or white), the magnitude of the difference between the average values of every two adjacent row segments and every two adjacent column segments are computed and compared to the requirement. Figure 2-10 illustrates the locations of some of the horizontal segments in a rolled impression print block image.

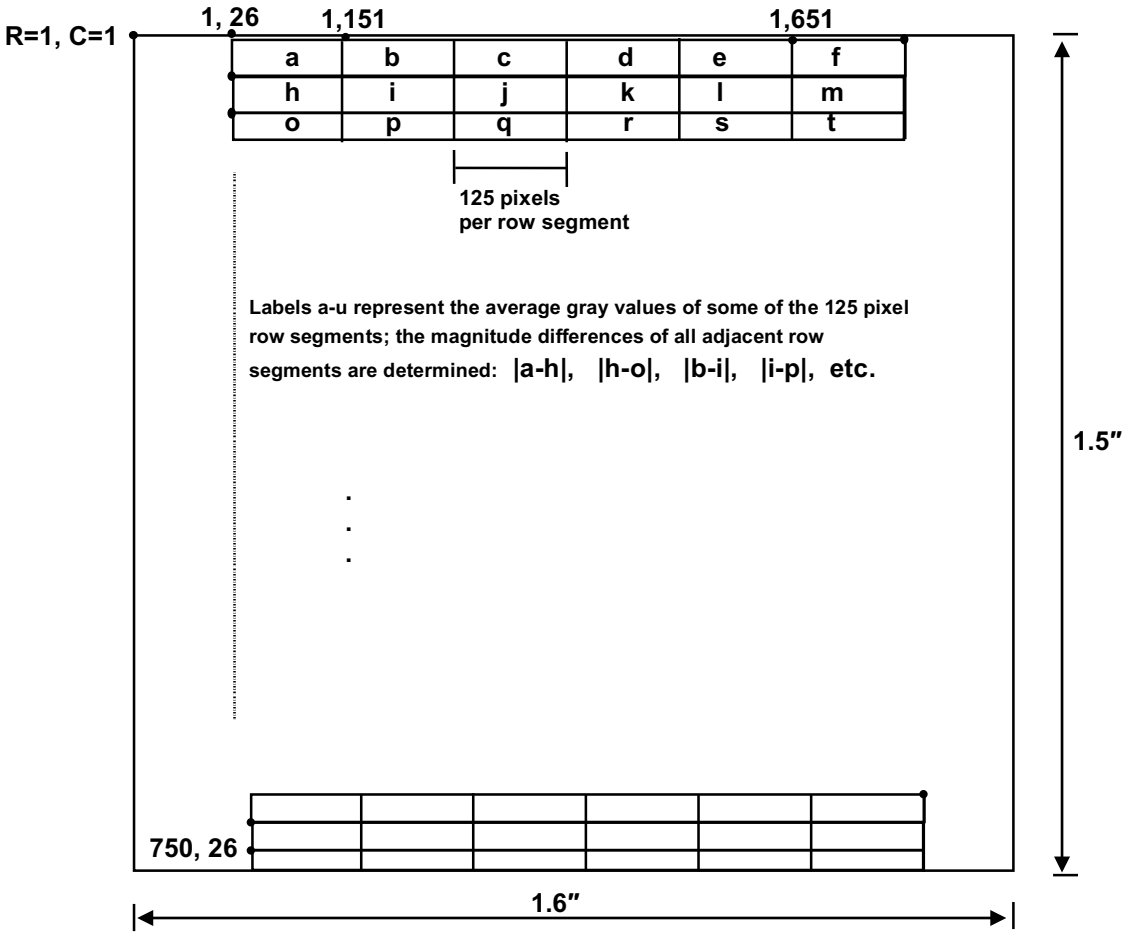

Figure 2-10. Example Measurements for Adjacent Row Uniformity Assessment (125 Pixel Long Row Segments in Rollblock, 500 ppi Scanner)

2.5.3.3 Pixel to Pixel Uniformity Test Procedure

The locations of all independent quarter-inch windows that fit within each printblock area are identified. For example, for a ten-print card scanner this produces 6 rows and 6 columns of quarter-inch windows for each rollblock, for a total of 36 windows per rollblock, 21 windows for each plain thumb block, and 84 windows for each 4-finger plain block. For a live scanner, all independent quarter-inch windows that fit within the total capture area are identified.

The average gray-level for each quarter-inch window, rounded to the nearest whole number (nearest integer value), is computed.

The absolute value of the difference between the average of a given quarter-inch window and each of the individual pixel values within that window is computed. For a 500 ppi scanner, there are 125 x 125 = 15,625 test values in each quarter-inch window.

2.5.3.4 Small Area Uniformity Test Procedure

The average gray-level for each quarter-inch window defined in Section 2.5.3.3 is recomputed, this time without rounding, producing a floating point number.

For a given target scan, the absolute value of the difference between the averages is computed for every possible pair of quarter-inch windows within each of the fourteen print blocks; or, for a live scanner, over the total image capture area. This difference is denoted as A_{white} for the white target cases and A_{black} for the black target cases. A_{white} and A_{black} each have 630 values for each rollblock (from 36 quarter-inch windows), 210 values for each plain thumb block (from 21 quarter-inch windows), and 3486 values for each plain four-finger block (from 84 quarter-inch windows).

Notes:

- The gray-level uniformity requirements can be verified with the *snr* software which is on the IQS Test Tools CD. [*Snr* avoids the area around the white/black target join line shown in Figure 2-9.]

- If, after careful cleaning of the target and scanner platen, a small quantity of measurement samples still contain residual artifacts, such as dust, pinholes, scratches, or smudges on the target, then these samples may be discounted from the final test sample size.

2.5.4 Requirements Compliance

The adjacent row, column uniformity requirements are complied with if, for each printblock area, at least 99% of the differences between the average values of adjacent quarter-inch long rows, and at least 99% of the differences between the average values of adjacent quarter-inch long columns, do not differ by more than 1.0 gray-levels when scanning a uniform low reflectance target, and do not differ by more than 2.0 gray-levels when scanning a uniform high reflectance target.

The pixel to pixel uniformity requirement is complied with if at least 99.9 percent of all of the pixels in each of the quarter-inch windows, within each imaged printblock area, is within 22 gray-levels of the window's mean gray-level for the white target image, and is within 8 gray-levels of the window's mean gray-level for the black target image.

The small area uniformity requirement is complied with if $A_{white} \leq 12.0$, for all of the A_{white} values within each imaged printblock area, and if $A_{black} \leq 3.0$, for all of the A_{black} values within each imaged printblock area.

[For a livescanner, the "printblock area" corresponds to the total image capture area.]

2.6 FINGERPRINT IMAGE QUALITY

2.6.1 Requirements

Fingerprint Gray Range:
At least 80% of the captured individual fingerprint images shall have a gray-scale dynamic range of at least 200 gray-levels, and at least 99% shall have a dynamic range of at least 128 gray-levels.

Fingerprint Artifacts and Anomalies:
Artifacts or anomalies detected on the fingerprint images, due to the scanner or image processing, shall not be significant enough to adversely impact support to the functions of conclusive fingerprint comparisons (identification or non-identification decision), fingerprint classification, automatic feature detection, or overall Automated Fingerprint Identification System (AFIS) search reliability.

Fingerprint Sharpness and Detail Rendition:
The sharpness and detail rendition of the fingerprint images, due to the scanner or image processing, shall be high enough to support the fingerprint functions of conclusive fingerprint comparisons (identification or non-identification decision), fingerprint classification, automatic feature detection, and overall Automated Fingerprint Identification System (AFIS) search reliability.

2.6.2 Target

A card scanner is tested with an FBI-supplied set of 8 x 8 inch, ten-print, inked fingerprint cards. These cards represent a set of stratified random samples drawn from the FBI's Fingerprint Card Master File (FCMF). This test card set consists of three strata: light-inked cards, medium-inked cards, and dark-inked cards. Appendix D describes the construction of a set of stratified card samples.

For 500 ppi testing, at least the 5 x 8 inch, 14 printblocks area should be scanned; for 1000 ppi testing it is sufficient to scan the 3 x 8 inch, 10 rollblocks area. In either case the entire 8 x 8 inch card may be scanned.

This card set includes a number of cards with difficult to handle properties; e.g., tears, holes, staples, glued-on photos, lamination, etc. If the card scanner is to be certified for

use with an Automatic Document Feeder (ADF), then an attempt should be made to feed all cards through the ADF for scanning. If some of the difficult to handle cards cannot be fed through the ADF, they should be scanned in whatever manual mode is available. It is expected that the vendor would then establish an exceptions handling procedure and this procedure would be conveyed to the user for operational employment.

For a live scanner operating at 500 ppi or 1000 ppi, the vendor seeking certification is responsible for supplying the following sets of livescans:

- For a standard roll and plain finger live scanner: capture a complete set of fingerprints from each of 10 subjects; i.e., 10 rolls (all 5 fingers from each hand), 2 plain thumb impressions, and 2 plain 4-finger impressions.

- For a palm scanner component of a live scan system: capture left and right palms from each of 10 subjects.

- For an Identification Flats live scanner: capture left and right 4-finger plain impressions and dual thumb plain impressions from each of 10 subjects.

For Fast Track testing, the vendor normally supplies 10 cardscans or livescan sets from 5 subjects.

The test cardscans or test livescans must be supplied in an uncompressed format such as raw, TIFF, or PGM format (not in NIST or EBTS format). Furthermore, these uncompressed images cannot have been previously compressed/decompressed via a lossy compression, such as WSQ.

2.6.3 Test Procedure

2.6.3.1 Fingerprint Gray Range

1) Whether scanning ten-print cards or livescans, the same basic methodology is used; i.e., a single subimage is first defined within the scanned image of each fingerprint block. This subimage is sized and positioned such that it includes a substantial part of the fingerprint, while excluding format lines, box lines, printed/handwritten text, and most of the white background. Figure 2-11 gives some examples of acceptable subimage sizing/positioning under several different conditions in a ten-print card. In some cases, a printblock-centered subimage of constant size (for each of the 4 printblock types) could fulfill the capture requirements.

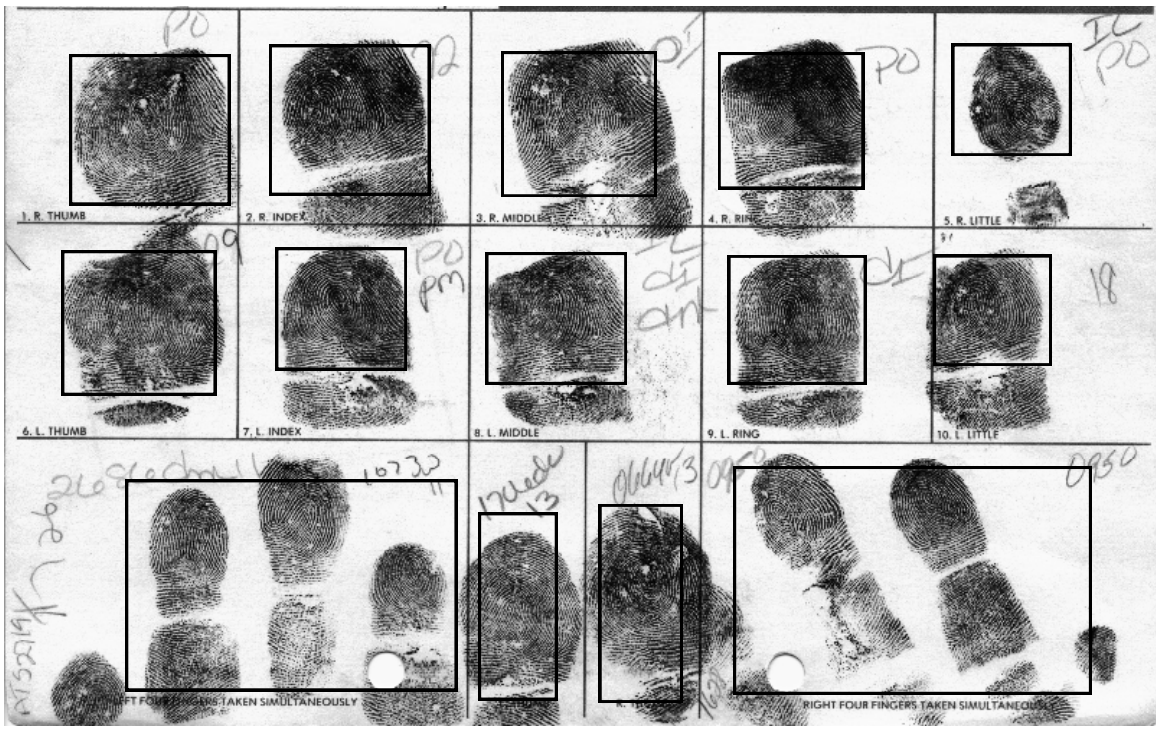

Figure 2-11. Example Measurement Boxes for Gray Range Assessment (Width/Height Ratio of Each Box is the Same as the Printblock Width/Height Ratio).

2) The gray range is computed for each of the subimages defined in step (1). The gray range is equal to the total number of gray-levels in the subimage which contain signal, where a gray-level bin is counted as containing signal if it contains at least a minimum number of pixels.

Background:

- Since a subimage contains hundreds of thousands to millions of pixels, the expectation is that if a given gray-level bin contains signal, then it would be populated by more than just a few pixels, since all signal pixels are spread out between no more than 256 gray-level bins. Therefore, if a gray-level bin contains very few pixels it is probably just noise; e.g., dark current, crosstalk, or amplifier noise. A threshold value of 5 pixels can be used to separate gray-level bins populated only by noise, from bins populated by signal (+ noise).

- The 8 bpp quantization of the gray-scale values for very low contrast fingerprints needs to more optimally represent the reduced gray-scale range of such fingerprints, which may require adaptive processing. The intent of such

processing would be to overcome excessively low contrast images without adding false detail.

- Note that the definition of gray range in this section is not, in general, equal to the simple difference between maximum gray-level and minimum gray-level.

3) For card scans, the subimages from the cards corresponding to each of the three strata are grouped together and a table such as the example case given in Table 2-6 is generated, from the computed dynamic ranges of the subimages in each stratum.

Table 2-6. Example 50 Card Test Results

Stratum	Number of Cards	Total Images	Number of Images with 1 to 127 Gray-Levels	Number of Images in 200-256 Gray-Levels	Stratum Weight
1 (light)	20	200	1	196	0.0314
2 (medium)	20	200	0	200	0.9628
3 (dark)	10	100	0	100	0.0058

The values in Table 2-6 are used to calculate the strata-weighted results, by first computing for each stratum:

(stratum weight) x (#images in gray range being calculated) / (total images in stratum)

and then summing over the three strata. Using the example values from Table 2-6, this procedure results in,

$$\geq 200 \text{ grays}: \quad \frac{(.0314)196}{200} + \frac{(.9628)200}{200} + \frac{(.0058)100}{100} = 0.9994 \qquad [\text{req} : > 0.800]$$

$$\geq 128 \text{ grays}: \quad \frac{(.0314)199}{200} + \frac{(.9628)200}{200} + \frac{(.0058)100}{100} = 0.9998 \qquad [\text{req} : > 0.990]$$

This analysis, which is described in more detail in Appendix D, is implemented in the *grayfinger* software, which is on the IQS Test Tools CD.

2.6.3.2 Fingerprint Artifacts and Anomalies

The fingerprint images will be examined to determine the presence of artifacts or anomalies due to the scanner or image processing. Artifacts and anomalies such as the following non-inclusive list may be investigated:

- jitter noise effects
- sharp truncations in average gray-level between adjacent printblocks
- gaps in the gray-level histograms; i.e., zero pixels in intermediate gray-levels, or clipping to less than 256 possible gray-levels
- imaging detector butt joints
- noise streaks
- card bleed-through
- excessive gray-level saturation

Due to the varied nature of potential artifacts and anomalies, there is no single test tool or analysis method that can be applied to all cases. As a first step, the fingerprint images are displayed and inspected for any obvious problems. If a significant artifact or anomaly is visually detected, then the next stage of analysis is to decide whether it is due to the input fingerprint (inked or live), or is due to the scanner/image processing combination; if it is due to the scanner/image processing combination, then appropriate image analysis techniques are applied to measure and quantify it. Other problems may not be obvious from visual assessment, for example, the *grayfinger* software on the IQS Test Tools CD detects and reports-out the existence of gray-level clipping, which may not be visually discernable.

2.6.3.3 Fingerprint Sharpness and Detail Rendition

The fingerprint images are displayed and inspected to determine their visual sharpness and detail rendition; e.g., by comparing a given image to others in the set, or comparing a given image to other compatible sets of images. Visual assessment can, for example, detect images that are significantly out-of-focus.

Assessments of sharpness and detail rendition can be quantified by applying a suitable objective quality metric. Although no definitive fingerprint quality metric is identified here, the following is a partial list of metrics which may be useful in this application. In applying any objective quality metric in this testing venue, it is important to keep in mind that the goal is to assess scanner quality, not input finger quality.

- The NIST *nfiq* fingerprint image quality software and documentation available for download at:
  http://www.itl.nist.gov/iad/894.03/nigos/nigos.html

- The MITRE *iqf* fingerprint image quality software and documentation available for download at:
  http://www.mitre.org/tech/mtf

2.6.4 Requirements Compliance

1) The fingerprint gray range requirement is met if at least 99 percent of the strata-weighted set of cardscan subimages, or unweighted subimages for livescans, have at least 128 gray-levels, and at least 80 percent of the same set of subimages have at least 200 gray-levels.

2) The artifacts and anomalies requirement is met if detected artifacts or anomalies, due to the scanner or image processing, are not significant enough to adversely impact support to the functions of conclusive fingerprint comparisons (identification or non-identification decision), fingerprint classification, automatic feature detection, or overall Automated Fingerprint Identification System (AFIS) search reliability.

3) The sharpness and detail rendition requirement is met if the sharpness and detail rendition of the fingerprint images, due to the scanner or image processing, is sufficient to support the functions of conclusive fingerprint comparisons (identification or non-identification decision), fingerprint classification, automatic feature detection, and overall Automated Fingerprint Identification System (AFIS) search reliability.

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SECTION 3

IDENTIFICATION FLATS SCANNER

3.1 Requirements

Inclusive:
All requirements stated in Section 2 apply.

Capture Protocol:
The system shall provide a simple capture protocol so that the inexperienced user consistently captures high quality fingerprints.

Verifiable Finger Sequence Data:
The fingers shall be captured in a way that eliminates the possibility of error in the finger numbers.

3.2 Background

Traditional fingerprint sets contain both rolled and plain fingerprint images. The rolled impressions support the search processing and identification functions and the plain impressions are used primarily for sequence verification. Fingerprint systems designed for Identification Flats civilian background checks capture a single set of plain impressions. This single set of plain impressions must support finger sequence verification, search processing, and identification.

Image quality has historically been a challenge for civil background checks. Some programs require a large number of relatively low volume capture sites, which makes training difficult. A key requirement for identification flats scanners is to reduce the training requirement so that inexperienced users consistently capture quality fingerprint images.

3.3 Test Procedures

The test procedures described in Sections 2.1 to 2.5, which utilize measurements on images of deterministic targets, are performed.

The test procedures described in Section 2.6 “Fingerprint Image Quality” are performed by assessments on the left and right 4-finger plain impressions and dual thumb plain impressions from each of 10 subjects.

The system will be evaluated for its ability to produce a very small rate of failure-to-enroll in an operational setting.

The fingerprint system capture protocol will be evaluated for its ability to capture verifiable finger sequence data.

3.4 Requirements Compliance

Inclusive:
All requirements stated in Section 2 shall be met.

Capture Protocol:
The requirement is met if the system has a minimum capture area of 3.2 inches (width) by 3.0 inches (height) and can capture 4 fingers simultaneously in an upright position. Other capture approaches will require specific testing and documentation.

Verifiable Finger Sequence Data:
The requirement is met if the system has a minimum capture area of 3.2 inches (width) by 3.0 inches (height) and can capture the left four fingers simultaneously, the right four fingers simultaneously, and the two thumbs simultaneously (4-4-2) in an upright position. Other capture approaches will require specific testing and documentation.

SECTION 4

FINGERPRINT PRINTER

In this section, the term “printer” refers to the combination of a physical printer, fingerprint printing algorithm, and print medium, which shall be paper or card stock. A required printer resolution is 500 ppi

Verification of the printer performance requirements is accomplished by evaluating the printer's life-size output prints of an FBI-designated test set of digitized FingerPrints (**FP**), and evaluating an FBI-designated digital test TarGeT (**TGT**). One component of the FP test set is printed in 10-print card format. Version A8 of the TGT is shown in Figure 4-1.

Requirements compliance verification is performed by a combination of visual assessments of the FP and TGT prints (aided by visual instruments such as magnifiers), and computer-aided assessments of scans of the FP and TGT prints. With respect to those requirements that depend on assessments of print scans for compliance verification, the scan resolution is expected to be twice the required print resolution; e.g., a 500 ppi print would be scanned at 1000 ppi, and the scanner would be setup in a calibrated linear input/output, grayscale reflectance capture mode.

For a non-laser printer, e.g., inkjet printer, it may be required to stipulate additional parameters that would become part of the certification listing, such as type of paper used, type/color of ink cartridges used, or user-controlled features of the printer which could affect image quality.

4.1 Spatial Frequency Response

4.1.1 Requirements

The printer shall provide sufficient spatial frequency response to support visually resolving the required printer resolution, in orthogonal directions on the print.

When an appropriate method for measuring the spatial frequency response curve is applied, that curve shall meet or exceed a minimally acceptable level, in orthogonal directions on the print.

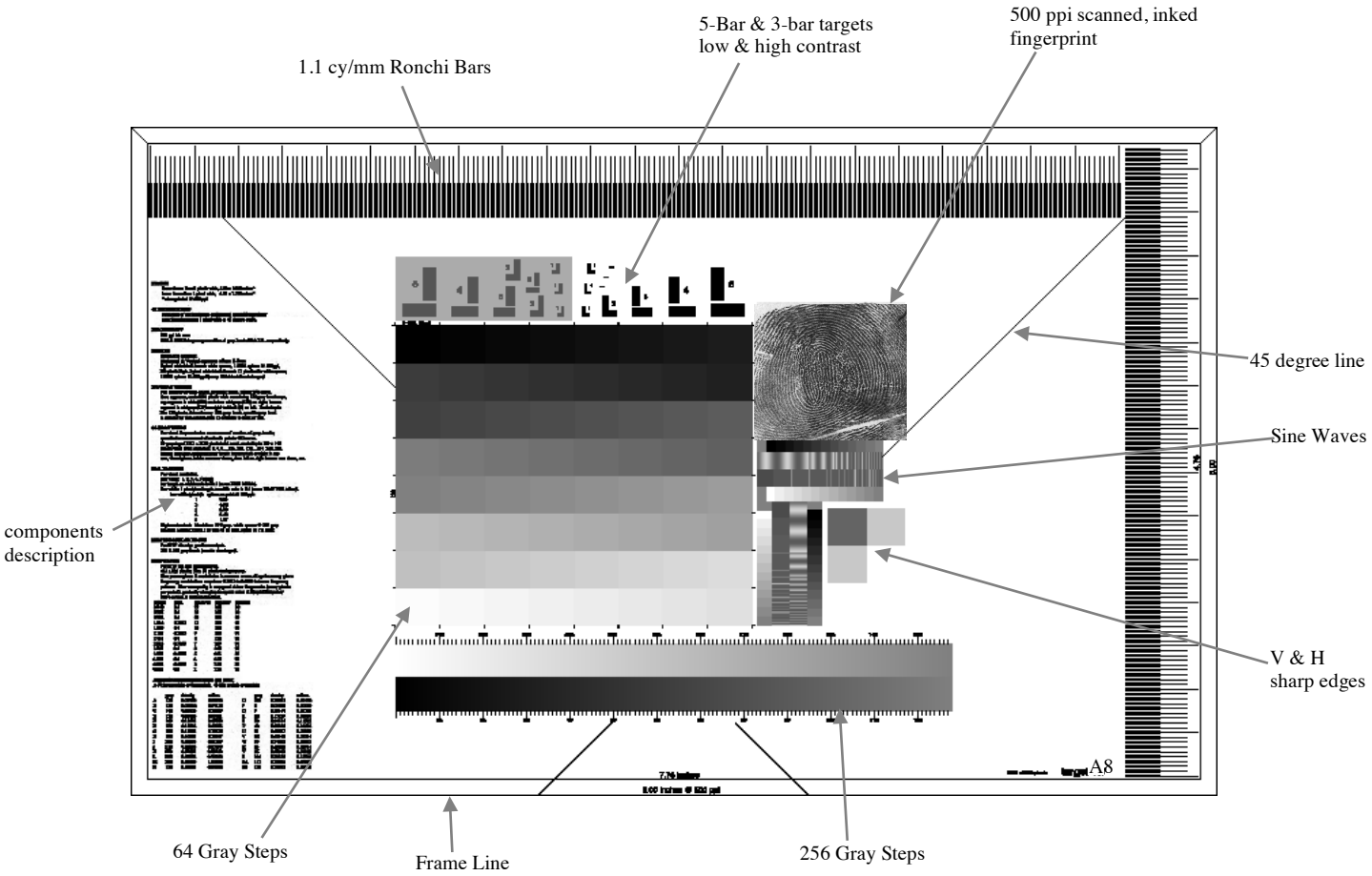


Figure 4-1. Printer Test Target (TGT)
(Version A8 Designed for Printing at 500 ppi, Outer Frame is 4000 by 2500 Pixels)

4.1.2 Test Procedures

When the TGT and the ten-print card format component of the FP test set are printed life-size, each print contains black/white parallel bar patterns corresponding to the spatial frequency of the required print resolution. For example, a fingerprint captured at 500 ppi has a limiting frequency of 250 cycles per inch and the corresponding FP and TGT prints would each contain 250 cycles per inch bar patterns.

The bar patterns at the limiting frequency are observed and a determination of resolvability is made with the aid of a magnifier, typically in the 4X to 10X magnification

range. Resolvability of a given bar pattern is a binary decision; i.e., it is either judged to be visually resolved or not resolved[10].

A bar pattern at the limiting frequency represents a single point on the printer's spatial frequency response curve. The entire spatial frequency response curve may be measured by scanning the print of an appropriate target and performing appropriate computer-aided assessment on the scan.

4.1.3 Requirements Compliance

At least half of all high contrast bar patterns[11] in each direction (vertical and horizontal), and at the spatial frequency corresponding to the required printer resolution, shall be visually resolved on the TGT print.

The vertical and horizontal direction bar patterns ("bar chart") in the FP prints shall be visually resolved.

When an appropriate target and computational method is used for measuring the spatial frequency response curve of the printer, the measured curve shall meet or exceed a minimally acceptable response curve.

4.2 Gray-levels

4.2.1 Requirements

At least 16 gray-levels shall be visually distinguishable on the print.

4.2.2 Test Procedures

The TGT is printed lifesize. TGT version A8 contains a 64 gray-step tablet, spanning the range from black (gray=0) to white (gray=252), with 3 gray levels between adjacent steps. Each gray-level step is large enough on the print to be individually distinguishable (~1/3 x 1/3 inch).

The observer counts the number of individually distinguishable steps on the print, utilizing the following guidelines:

- place a blank, white sheet of paper underneath the print

---

[10] Guidance on judging resolvability can be found in the international standard: *Micrographics - ISO Resolution Test Chart No. 2 - Description and Use*, ANSI/AIIM MS51-1991 and ISO 3334:1991.

[11] One "bar pattern" is a set of equal-width, adjacent, parallel bars corresponding to a specific spatial frequency.

- use adequate, non-glare room lighting
- in some cases a low power magnifier (~2X)[12] may aid assessment
- a given visual gray-level is only counted once, even though it may appear in more than one step
- do not count a visual gray level that is out-of-sequence
- count as a single gray level, all adjacent steps (two or more) that appear to have the same gray level
- concentrate on the central area of a step for assessment; this is particularly necessary if the print exhibits noticeable edge enhancement.

4.2.3 Requirements Compliance

At least 16 gray-levels shall be visually distinguishable on the print.

4.3 Dynamic Range

4.3.1 Requirements

The printer shall have the capability to print an input digital image gray range of at least 130, excluding print black saturation and print white saturation.

4.3.2 Test Procedures

The print of a digital step tablet is scanned; e.g., the 64 step tablet in TGT version A8. Each pixel's output gray-level value is converted to the corresponding print reflectance value, and the average print reflectance value within each step is computed. A plot of step average print reflectance versus input digital step tablet gray level is constructed, as illustrated in Figure 4-2.
[The scanner output gray-level to print reflectance conversion must first be established by generating the scanner's input/output curve using a calibrated step tablet. The dynamic range can then be verified by plotting the output of the *step64* software, which is on the IQS Test Tools CD.]

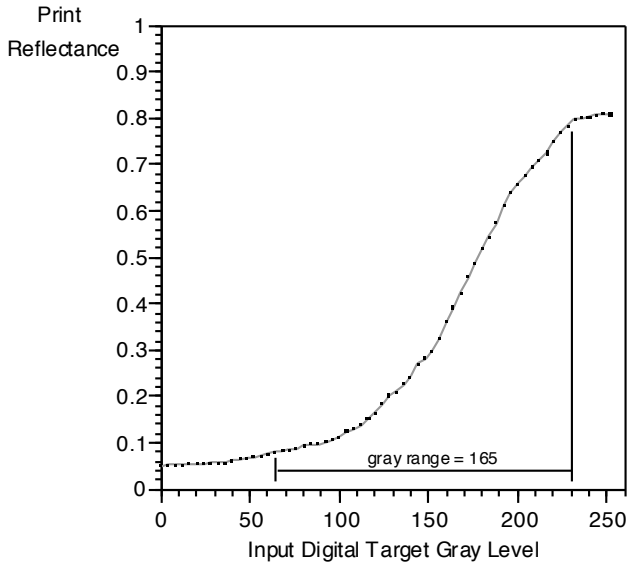
4.3.3 Requirements Compliance

Excluding any saturation on the low end (print black reflectance) and high end (print white reflectance), the remaining print reflectance range shall correspond to a target gray range of at least 130 gray levels. The following is a deterministic method used for excluding saturation effects.

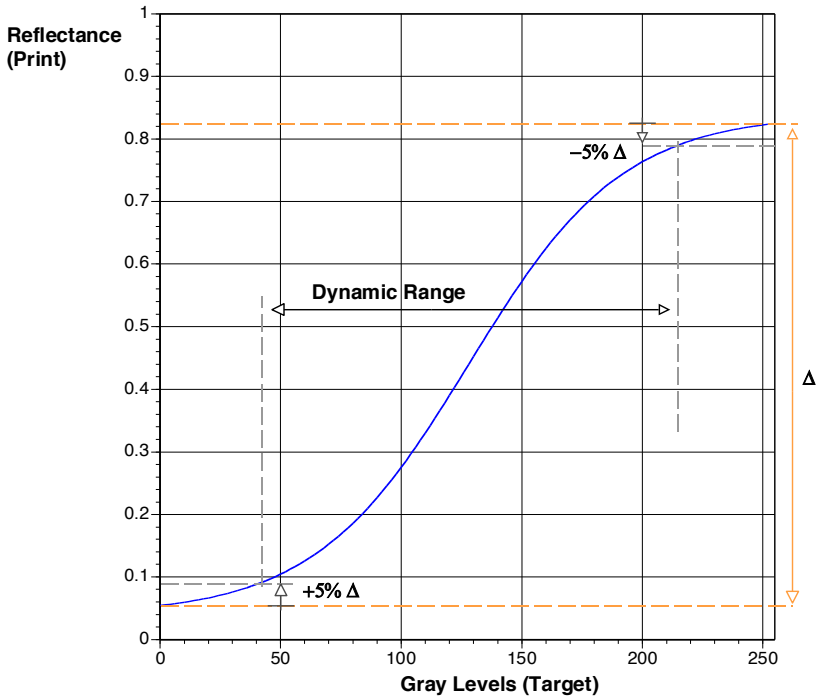
---

[12] A 2X magnifying power means that the object appears to the eye to be 2 times larger than it would appear to the unaided eye at normal reading distance.

Let delta be the difference in Reflectance values between the highest and lowest saturation values of an ideal S-shaped curve. The low threshold of the dynamic range is defined as being 5% of delta above the low saturation value of the S-shaped curve. The high threshold of the dynamic range is defined as being 5% of delta below the high saturation value of the S-shaped curve. The difference between the high threshold and the low threshold values is the dynamic range. Departure from the ideal S-shaped curve (bumps and dips) will be assessed on a case-by-case basis.



(a)



(b)

Figure 4-2. Print Dynamic Range Measurement

4.4 Geometric Accuracy and Print Scale

4.4.1 Requirements

When printing a digital bar target containing parallel bars, then the absolute value of the difference (D), between the measured distance (Y) across the parallel bars on the print, and the correct distance (X) on the print, shall not exceed the values for D given in Table 4-1, for at least 97% of the tested "short distance" and "medium distance" cases in each direction (vertical and horizontal).

The average of all "medium distance" test cases, in each direction, shall not exceed the corresponding values for D given in Table 4-1.

The average of all "long distance" test cases, in each direction, shall not exceed the corresponding values for D given in Table 4-1.

Straight target lines printed parallel to, or at a 45-degree angle to, the paper or card edges, shall be straight on the print, with no significant waviness, bow, or staircasing.

Table 4-1 Geometric Accuracy Requirements

Distance Error (D)	Distance Range (X)	Comment
$D \leq 0.001$	$0.00 < X \leq 0.07$	short distance
$D \leq 0.015X$	$0.07 < X \leq 1.50$	medium distance
$D \leq 0.010X$	$4.75 < X \leq 8.00$	long distance

Table Note: $D = |Y-X|$
X = correct distance = digital target pixels / required print resolution
Y = measured distance on print
D, X, Y are in inches

4.4.2 Test Procedures

The TGT is printed lifesize. Target version A8, when printed at 500 ppi, contains a 7.1 inch long segment of parallel vertical bars and a 4.7 inch long segment of parallel horizontal bars on the print,[13] where the bar frequency is: 500 / (25.4*18) = 1.0936

[13] These bar patterns actually contain two components, either one of which could be used for requirement compliance testing: (1) parallel bars with equal bar and space widths at 1.0936 cy/mm, known as a Ronchi target, and (2) narrow, parallel bars with wide spaces, also at 1.0936 cy/mm. The *geo* software operates on the equal bar and space Ronchi bar pattern.

cy/mm. The TGT also contains frames lines around the border and lines at a 45 degree angle to the target edges.

Assessment of the short distance and medium distance geometric accuracy, and medium distance print scale, requires that the print be scanned at 1000 ppi. When the print is oriented such that the bar lengths in the bar segment to be measured are in-line with the scanner's direction of scan, as illustrated in Figure 4-3, then scanner-induced perturbations are minimized (this requires 2 scans to capture the two orthogonal Ronchi segments, with a 90 degree rotation of the print on the scanner bed between scans). The scanner's output digital image can then be input to the *geo* software, supported by *creategeofile* and *viewgeo* software, which are on the IQS Test Tools CD. See Appendix C for a detailed description of the computations performed in *geo*.

Assessment of the long distance print scale can be performed manually, measuring the distance between the 8 x 5 inch frame lines and/or 7.75 x 4.75 inch frame lines (left/right and top/bottom frame lines), with the aid of a precision ruler and magnifier. The % scale error in the print can be computed from:

$$\%\ \text{scale error} = \frac{100\,|\,\text{printwidth} - \text{targetwidth}\,|}{\text{targetwidth}}$$

where,

$$\text{targetwidth} = \frac{\text{number of pixels between 2 parallel, vertical frame lines}}{\text{target ppi}}$$

printwidth = measured width on print between the same 2 parallel, vertical frame lines that are used in calculating the targetwidth

Line straightness can be assessed manually, by inspecting the vertical and horizontal framelines and 45 degree lines, with the aid of a straight-edge and magnifier.

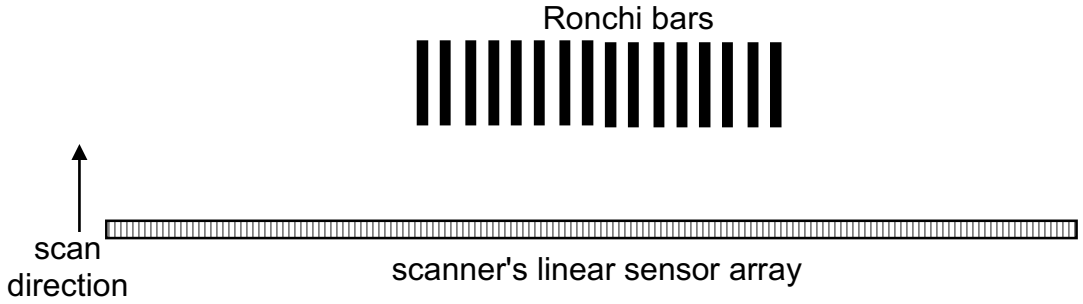


Figure 4-3. Correct Orientation of Print Ronchi Bars with Respect to Scanning Array

Background:

For the short and medium distance measurements and 500 ppi print resolution, a digital bar target with a period of 18 pixels is used, which corresponds to a bar frequency of 1.0936 cy/mm on the print, when printed life-size. The measured distance on the print can be obtained by scanning the print and applying computer-assisted assessment on the resulting digital image. The allowable short distance and medium distance errors given in Table 4-2, take into account the geometric errors inherent in a good quality scanner.

Medium distance print scale is measured from the bar target, where the ±1.5% allowable average error corresponds to an allowable print ppi range of 492.5 to 507.5 ppi. Due to the averaging and balancing-out of random, plus/minus medium distance scale errors, it could reasonably be expected that the long distance scale error would be less than the ±1.5% error allowed for medium distance. Therefore, long distance print scale, measured between the vertical and horizontal frame lines of the TGT, has an allowable ±1.0% average error in each direction.

Table 4-2. Geometric Accuracy Tests

Distance Measurement	Correct Distance (inches)	Directional Requirement Met if:
Short distance (1-bar)	0.0360	≥ 97% in range: 0.0350 to 0.0370
Medium distance (6-bar)	0.2160	≥ 97% in range: 0.21276 to 0.21924 avg in range: 0.21276 to 0.21924
Long distance (frame lines)	 8.000 5.000 7.7500 4.7500	avg in range: 7.9200 to 8.0800 4.9500 to 5.0500 7.6725 to 7.8275 4.7025 to 4.7975

Note: 500 ppi print with 1.0936 cy/mm bars.

4.4.3 Requirements Compliance

The short distance and medium distance geometric accuracy requirements are complied with if at least 97 percent of the tested cases in each direction (vertical and horizontal), in

each distance range, are within the minimum and maximum distance limits defined in Table 4-2.

The medium distance print scale requirement is complied with if the average distance in each direction (vertical and horizontal) is within 1.5% of the correct distance, which is equivalent to the average ppi being between 492.5 and 507.5.

The long distance print scale requirement is complied with if the average distance in each direction (vertical and horizontal) is within 1.0% of the correct distance.

The line straightness requirement is complied with if inspection of the long vertical and horizontal frame lines, and the 45 degree lines, indicates that these lines are straight, with no significant waviness, bow, or staircasing.

4.5 Noise

4.5.1 Requirements

For a required printer resolution of 500 ppi, the noise magnitude shall be less than 0.120 at all print reflectance levels, when noise magnitude is defined as the standard deviation of print reflectance values within an area on the print corresponding to a constant gray level on the input digital target. [Print reflectance measured in fractional units: 0.0 to 1.0 range.]

4.5.2 Test Procedures

The TGT is printed lifesize and noise assessment is applied to the 64-gray step tablet as follows:

1) A calibrated reflection step tablet[14] is scanned in a flatbed scanner at 1000 ppi and the scanner is adjusted to obtain a linear or near-linear relation between target reflectance and scanner output gray-level; the curve of best fit is determined for this relation, with target reflectance as the independent variable.

2) The print of the TGT is scanned at 1000 ppi on the same scanner, setup in its calibrated mode.

3) The standard deviation in reflectance units is computed for each of the 64 steps, using the scanner output digital image and the scanner calibration curve. [The *step64* software on the IQS Test Tools CD performs these computations.]

[14] Reflection step tablets, where each step is calibrated in density or reflection units, are commercially available - see Appendix B.

4.5.3 Requirements Compliance

Each of the 64 computed standard deviations of print reflectance values shall be less than 0.120.

4.6 Print Polarity and Color

4.6.1 Requirements

The printed fingerprints shall appear as dark gray-to-black ridges on a light gray-to-white background.

4.6.2 Requirements Compliance

The printed fingerprints are visually inspected for compliance with the requirement.

4.7 Print Permanence

4.7.1 Requirements

The printed fingerprints shall not smear or smudge with normal handling.

4.7.2 Requirements Compliance

Compliance testing may consist of: (1) using moderate finger pressure to rub a fingerprint area of the print and then establish whether or not any visually apparent smearing or smudging of the fingerprint has occurred, and (2) adding a drop of water to a fingerprint area of the print, allowing it to dry undisturbed, and then establish whether or not any visually apparent smearing or smudging of the fingerprint has occurred.

Prints on paper or card stock from a standard laser printer[15] meet the print permanence requirement without testing, as do prints on paper or card stock from any other type of printer that has print permanence characteristics equivalent to or better than a laser printer.

4.8 Print Stability

4.8.1 Requirements

[15] "Standard laser print system" here refers to a type of print system in which a laser beam "draws" an electrostatic image of an input signal onto a drum. Black toner (typically dry powder) is then transferred to the charged areas of the drum, which then transfers the toner onto paper, where it is fused by heat, creating a black/white/gray image.

Both the printed fingerprints and the card stock or paper on which they are printed shall retain their visually neutral (black, white, gray) color over time.

4.8.2 Requirements Compliance

Prints on paper or card stock from a standard laser printer meet the print stability requirement, as do prints on paper or card stock from any other type of printer that has stability characteristics equivalent to or better than a laser printer.

4.9 Hazardous Materials

4.9.1 Requirements

The prints shall not produce any health hazard as a result of handling. They shall not produce any noxious, annoying, or unpleasant odors when accumulated in large numbers and handled in areas having limited ventilation.

4.9.2 Requirements Compliance

Prints on paper or card stock from a standard laser printer meet the hazardous materials requirement, as do prints on paper or card stock from any other type of printer whose negative impact on health is no worse than a laser printer.

4.10 Fingerprint Prints

4.10.1 Print Types Requirements

The printer shall have the capability to print a set of individual livescans or previously scanned, individual inked fingerprints, life-size and in their correct printblock locations, onto a standard ten-print fingerprint card (e.g., fingerprint card type FD-258), or print onto blank 8.0 x 8.0 inch card stock, or print onto blank 8.5 x 11.0 inch plain paper. In the case of printing fingerprints onto blank card stock or blank paper, the printer shall also print the printblock boundary lines and labeling that normally appears on a standard ten-print card.

The printer shall have the capability to print a previously scanned ten-print card, in its entirety and life-size, onto blank 8.0 x 8.0 inch card stock, or onto blank 8.5 x 11.0 inch plain paper.

NOTE: Printer margins for edge adjacent printblocks when printing on 8.0 x 8.0 inch card stock may not exceed 10% of the image width dimensions. For an image 1.5 inches wide, this means a margin of 0.15 inches or less. In worst case, truncation of card edges is acceptable. Any shrinkage resulting in image reduction is unacceptable.

The printer shall have the capability to print a single fingerprint, magnified up to 5 times beyond life-size, onto 8.5 x 11.0 inch plain paper.

4.10.2 Requirements Compliance

The prints of the FP are visually inspected for conformance with the requirements.

4.11 Auxiliary Print Data

When printing in ten-print card format onto ten-print card stock, blank card stock, or plain paper, the printer shall also have the capability to print labels, bar chart, step tablet, and finger condition codes, all on the same print with the fingerprints. Figure 4-4 illustrates the printing of this auxiliary information; the following sections, 4.11.1 through 4.11.4, give the detailed requirements.

4.11.1 Labels

4.11.1.1 Requirements

When printing fingerprints in ten-print card format, the printing process shall have the capability to print a character string of scanner information within the left four finger plain impression printblock, and a character string of printer information within the right four finger plain impression printblock. Each character string shall be printed along the top inside edge of the respective printblock, in a type font and size that is large enough for human readability without the aid of a magnifier, and small enough so as not to unduly impinge on fingerprint structure; i.e., height of upper case letter or numeral in the range: 0.067 inches to 0.095 inches.

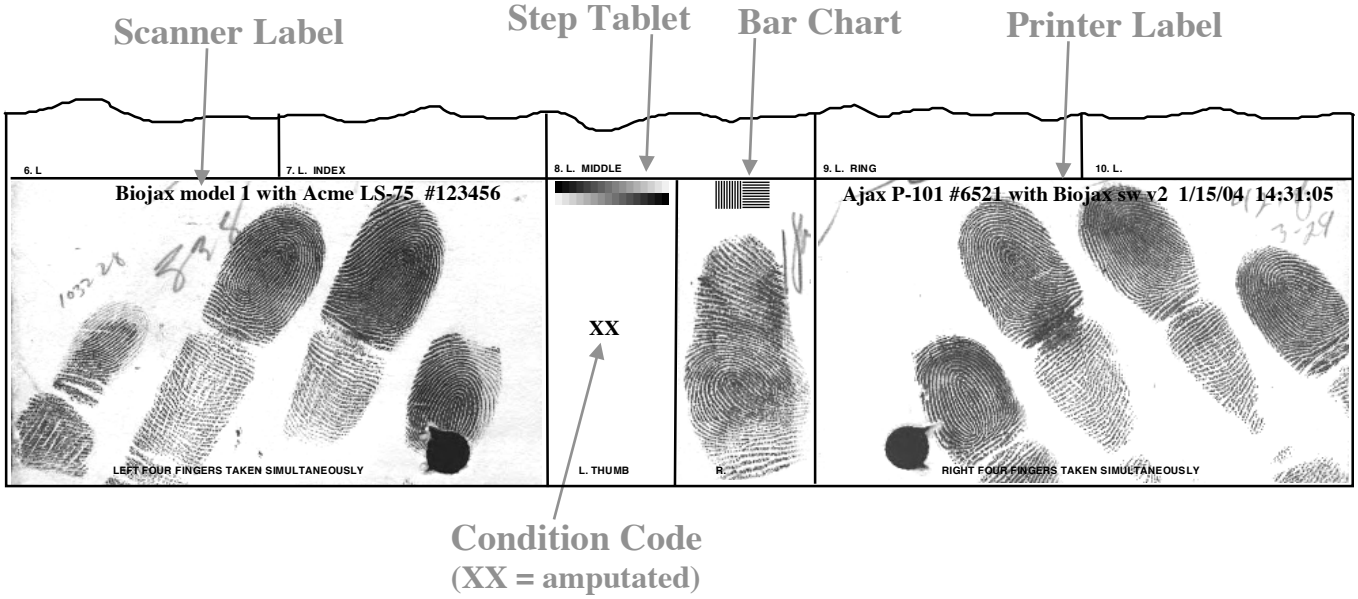


Figure 4-4. Auxiliary Information in Ten-Print Card Format Print (Example Text)

The scanner information string shall include the following:
1) scanner make, model number, and serial number, if available
2) scanner system make, model number, and serial number, if available.

The printer information string shall include the following:
1) printer make, model number, and serial number, if available
2) name and version of the fingerprint printing algorithm, if available
3) date and time of printing.
The scanner and printer character strings shall be printed without a background, border, or any other type of added surround.

Background:

Information for the scanner string can typically be obtained from the [EBTS] Type-2 Record Field identified as "IMA 2.067 - Image Capture Equipment", which includes scanner system make, model number, and serial number.

A printer is certified as a combination of a specific brand/model printer and fingerprint printing algorithm; the latter may also have a name or version designation.

Character string printing: a solid background (e.g., white) to the character string is unacceptable because it would unnecessarily obliterate some parts of fingerprints on some images. Individual characters with no background that overprint the fingerprint, would obliterate a much smaller proportion of the fingerprint and are acceptable. Printing the character strings in an open space created by off-setting printblocks 6-10 from printblocks 11-14 is unacceptable because it changes the dimensions of the standard ten-print card format, and it cannot adequately accommodate fingerprints that stray across printblock boundaries.

4.11.1.2 Requirements Compliance

The prints of the ten-print card format component of the FP are visually inspected for conformance with the label content, size, and location requirements, aided by a magnifier and precision ruler, where necessary.

4.11.2 Bar Chart

4.11.2.1 Requirements

When printing fingerprints in ten-print card format, the printing process shall have the capability to print a bar chart, consisting of equally-spaced horizontal bars and equally-spaced vertical bars, whose spatial frequency equals the required printer resolution.

The Bar Chart shall be positioned at the top edge within the right thumb plain impression printblock and shall have a maximum width of 0.8 inches and a maximum height of 0.125 inches. The Bar Chart shall contain at least 10 parallel bars in each direction, vertical and horizontal, with a bar length of at least 0.0625 inches (not necessarily the same number of bars, or same bar length, in the two directions).

An optional, uniform mid-grey level patch may be included between the horizontal and vertical bar components.

The bar chart shall be printed without a border or any other type of added surround.

Background:
For a 500 ppi printer requirement the limiting frequency is 250 cycles per inch, which implies that 250 black bars per inch are printed**,** where the 0.002 inch width of an individual bar is equal to the width of the white space between two bars.

If a mid-gray patch between the vertical and horizontal bar patterns appears to have the same overall gray-level on the print as the two bar patterns, then this may indicate that the printer gamma/highlight/lowlight settings are optimum and/or that the printer toner supply was adequate for printing.

4.11.2.2 Requirements Compliance

The prints of the ten-print card format component of the FP are visually inspected for conformance with the bar chart content, size, and location requirements, aided by a magnifier and precision ruler, where necessary.

4.11.3 Step Tablet

4.11.3.1 Requirements

When printing fingerprints in ten-print card format, the printing process shall have the capability to print a step tablet, consisting of two adjacent horizontal bands, each band having 16 gray-levels. One band should progressively darken from left to right and the other band should progressively darken from right to left. The 16 digital input gray-levels corresponding to one band shall be identically the same as for the other band, and both bands should cover the total gray-level range. This step tablet shall be positioned at the top edge within the left thumb plain impression printblock and shall have a total width between 0.5 inches and 0.8 inches, and a total height between 0.0625 inches and 0.125 inches.

The step tablet shall be printed without a border or any other type of surround.

Background:
If the top band and bottom band appear to be balanced on the print, i.e., the same mid-gray-level appears in the middle of both the top and bottom bands, then this may indicate that the printer gamma/highlight/lowlight settings are optimum.

4.11.3.2 Requirements Compliance

The prints of the ten-print card format component of the FP are visually inspected for conformance with the step tablet content, size, and location requirements, aided by a magnifier and precision ruler, where necessary.

4.11.4 Finger Condition Codes

4.11.4.1 Requirements

When printing fingerprints in ten-print card format, the printing process shall have the capability to notate the presence of an abnormal finger condition in the appropriate printed fingerprint block, for those cases where the [EBTS] Type-2 Record Field identified as "AMP" (amputated or bandaged) is available, and/or for those cases where similar information is available from other sources, such as a state system (possibly with other notation codes).

4.11.4.2 Requirements Compliance

The prints of the ten-print card format component of the FP which have abnormal finger conditions, and for which finger condition codes are available, are inspected to verify the required presence and correct locations of the condition codes.

4.12 Fingerprint Quality

4.12.1 Requirements

The printer shall produce sufficient print quality to allow usable viewing of life-size fingerprint prints under magnification to support fingerprint comparisons, *i.e.*, identification or non-identification decisions. The lifesize print shall maintain its sharpness and detail rendition structure up to at least 4X visual magnification, to the extent that ridges, and ridge joints, bifurcations, and terminations that exist in the digital image input to the printer, can be substantially discerned by the human observer on the output print, without breaking-up and without getting lost in the noise. In addition, the

printing process shall not create significant false detail; e.g., shall not create ridge-like patterns which did not exist in the input digital image.

4.12.2 Test Procedure

The prints of the FP are visually inspected with the aid of a magnifier, looking at items such as:

- completeness of ridge patterns, in comparison to FP
- contrast, brightness, dynamic range, in comparison to FP
- artifacts, including false fingerprint structure, in comparison to FP
- capability of a life-size print to withstand 4X (or greater) magnification, without the magnified image appearing to break-up or to get lost in the noise.

The prints of the FP may be quantitatively assessed by applying an appropriate image quality metric to scans of the prints.

4.12.3 Requirements Compliance

Compliance with the requirements is obtained if the visual inspection of the FP prints, and any appropriate quantitative measurement that may be applied, results in the determination that sufficient image quality exists to allow usable viewing of life-size-printed fingerprints up to 4X visual magnification, to the extent that a substantial portion of the ridges, and ridge joints, bifurcations, and terminations that are in the FP, can be discerned on the print without breaking-up and without being lost in the noise, and no significant amount of false detail is discernible.

SECTION 5

MOBILE ID

A mobile identification (ID) device is a livescanner viewed in the context of a portable biometric acquisition station, i.e. one that is not intended to be stationary and hardwired to a much larger system used for comparing or matching biometric samples. Since mobile devices may satisfy a variety of collection modalities with differing image size and accuracy requirements, there is a set of subject acquisition profiles for fingerprint images, labeled 10-60, shown in Table 5-1. More information on the profiles and best practices associated with mobile ID systems can be found in [MobileID].

5.1 Requirements

Image Size/Impression Type:
For a given fingerprint acquisition profile (FAP),[16] the minimum image dimensions and full range of simultaneous number of fingers specified in Table 5-1 shall be met. The device shall be able to collect flat impressions. Rolled acquisition is optional.

Image Quality:
All requirements stated in either the [PIVspec] or Section 2 apply, as shown in Table 5-1. When the IQS specification is PIV, then all requirements in the [PIVspec] shall be met. When the IQS specification is App F, then all requirements in the [EBTS] Appendix F Section 2 shall be met.

Table 5-1. Mobile ID IQS Requirements

Fingerprint Acquisition Profile (FAP)	Minimum Image Dimensions (WxH in inches)	IQS Specification Requirements	Simultaneous # of Fingers
10	0.5 x 0.65	PIV	1
20	0.6 x 0.8	PIV	1
30	0.8 x 1.0	PIV	1
40	1.6 x 1.5	PIV	1-2
45	1.6 x 1.5	App F	1-2
50	3.2 x 2.0	App F	1-4
60	3.2 x 3.0	App F	1-4

[16] Prior to January 2012, Mobile ID terminology of Fingerprint Acquisition Profile (FAP) was referred to as Subject Acquisition Profile (SAP).

5.2 Background

FAPs 10, 20 and 30 are for single finger sensors with FAP 10 having the same minimum image dimensions as the Federal Information Processing Standard (FIPS) 201. FAPs 40 and above support simultaneous capture which is faster, reduces sequence errors and produces higher quality images. As detailed in [MobileID] an agency will select a FAP based on their specific requirements.

5.3 Test Procedures

Test procedures from [PIVtest] and Section 2 of this document will be applied, respectively. Plain impressions containing typical simultaneous collections from both the left and right hands of 10 subjects will be assessed for fingerprint image quality as described in the above references. Some of the tested images will contain the maximum number of simultaneous fingers listed in Table 5-1.

5.4 Requirements Compliance

Image Quality:
All requirements stated in Section 2 or [PIVtest], respectively, shall be met.

Image Size/Impression Type:
The requirement is met if the system has minimum capture dimensions in both width and height and can capture the required number of fingers (Table 5-1) simultaneously.

SECTION 6

FAST-TRACK CERTIFICATION

In certain defined cases full IQS certification testing, i.e., testing of all IQS requirements, is not required. In these cases Fast Track testing, i.e., testing only some of the IQS requirements, is sufficient.

6.1 Requirements

Fast Track certification testing is sufficient when:

• A vendor adds 'value' to an already-certified device, for example, by integrating additional software which may include firmware (SW) and/or hardware which may include firmware (HW), and repackaging the combination to create a value-added reseller (VAR) label system. However, if there is a reasonable expectation that the added SW, HW, or repackaging will affect the image quality performance of the original certified device, then full certification testing would be required.

• A vendor makes relatively minor modifications to a previously certified device. For example, a membrane is added to (or deleted from) a certified livescanner, an automatic document feeder is added to a certified manual-feed cardscanner, or a 1000 ppi certified scanner is operated at 500 ppi, using the same optics, sensor, and illumination.

Table 6-1 presents the test data requirements for some common Fast Track certification scenarios; for test requirements for other scenarios contact the FBI.

In addition to the test data, the vendor seeking Fast Track certification must provide a written statement to the FBI (letter or email) which affirms that the previously certified fingerprint device has not been changed, with respect to device functions, hardware, firmware, or software that could reasonably be expected to affect image quality performance[17]. Specific to a scanner, the optics and optical layout, sensor, illumination, image capture electronics and signal processing have not been changed and the maximum capture area has not been increased.

No certification testing is necessary when:

• The original recipient of a certification wishes to change the model name and there are no other changes to the certified product.

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[17] Except for inherent image quality changes in specific situations, e.g., when recertifying a 1000 ppi scanner at 500 ppi.

• The original recipient of a certification wishes to repackage the device, if there is a reasonable expectation that the repackaging will not affect the image quality performance of the device. All device HW/SW components which may affect image quality performance must remain the same as they were when originally certified. For example, repackaging a device into a ruggedized cabinet, or repackaging a floor-standing device as a desktop device by separating-out the host computer would not necessarily require further testing, but changing the optical path or optical train of elements to accommodate the repackaging would normally require retesting.

• A reseller of a certified device wishes to sell the device under its own label, or under the original label. The certified device must remain intact, unmodified, and as a stand-alone product with no added HW/SW. If relabeled by reseller, the certification is only valid when that label does in fact contain the originally certified device, i.e., no blanket certification for rebrands[18].

• An end user receives a certified device to be used 'as is', without modification (an end-user does not need its own certification).

Definition of Terms:

Vendor - generic term to include Original Equipment Manufacturer (OEM), reseller, Value-Added Reseller (VAR), product assembler, systems integrator, and similar.

Full IQS Certification - a complete set of test data covering all IQS requirements is submitted

Fast Track IQS Certification - a partial set of test data covering defined IQS requirements is submitted

[18] If there is no Fast Track testing, the device will not be listed under the resellers name in the FBI certification list. Instead it will remain listed / certified under the original vendor and device name. A separate reseller listing requires some Fast Track data.

Table 6-1. Fast Track Certification Procedures (Common Scenarios)

Fast Track Certification	Type	Test Data to be Provided to FBI	Requirements Compliance
Livescanner	Vendor A incorporates vendor B's certified device into vendor A's value-added system. Vendor adds (or deletes) platen membrane to certified device.	Livescans from 5 subjects (10 rolls & 4 plains, each subject). Sinewave or bar target scans (target supplied by vendor) and livescans from 5 subjects (10 rolls & 4 plains, each subject).	section 2.6 sections 2.1, 2.3 & 2.6
Cardscanner	Vendor A incorporates vendor B's certified device into vendor A's value-added system.	Fifty 10-print card scans (cards supplied by FBI)	section 2.6
Cardscanner with Automatic Document Feeder (ADF)	vendor recertifies manual card scanner for use with ADF	Fifty 10-print card scans (cards supplied by FBI)	section 2.6
Printer	Vendor A incorporates vendor B's certified device into vendor A's value-added system.	Print of printer test target (target supplied by FBI)	all subsections under section 4.0 pertaining to digital test target
1000 ppi fingerprint scanner as 500 ppi fingerprint scanner	vendor recertifies its own fingerprint scanner in alternate operating mode	Cardscanner: Sinewave target scans (target supplied by vendor) and ten 10-print card scans (cards supplied by FBI) Livescanner: Sinewave or bar target scans (target supplied by vendor) and livescans from 5 subjects (10 rolls & 4 plains, each subject)	sections 2.1, 2.3 & 2.6

6.2 Fast Track Permission

If the FBI agrees that the modifications present are not expected to adversely impact image quality performance, then Fast Track testing can proceed.

In the case of certain optical modifications, it may be necessary to perform different combinations of the IQS tests. For example, optics changes with no geometric effect (addition of a membrane, or changed illumination) would not require new geometry tests.

Often Fast Track is applied during the testing of a single device that serves several purposes. For example, a device that shares optics for 1000ppi and 500ppi should have full testing for 1000ppi, and may use Fast Track testing (sine or bar-targets and reduced number of livescans) for 500 ppi.

If the same optics are shared for tenprints and Identification Flats, then test targets for the larger scan area must be provided. However if the sine/bar targets are small enough that multiple placements are required, at least one should be placed in the area where the rollscans are acquired.

6.3 Test Procedures

Perform each of the individual tests included in the Fast Track as described in sections 1-5. When possible new test results will be compared to the previous certification test results to ensure no unexplainable changes occur.

6.4 Requirements Compliance

The Fast Track requirement is complied with if the necessary paperwork is provided, Fast Track permission is granted, the individual fast track tests meet compliance requirements, and there is no unexplainable difference from the previous compliance testing data.

SECTION 7

ADDITIONAL / OPTIONAL TESTS

In certain livescanner cases, additional data is requested.

7.1 Inked Card Comparison for New Designs

New sensing approaches that have not previously been certified or previously certified sensing approaches that are implemented in a creative way may benefit from an inked card comparison, where both inked cards and livescans from the new design are collected from the same subjects for comparison. These images are inspected by fingerprint examiners who provide commentary on ease of use and their comfort with the visual appearance of the prints. If the images produced by the new design cause the examiner discomfort that cannot be resolved or show signs of changes in print features, this situation can be a significant deterrent in certifying the new design.

The test data consists of prints from the same people, taken with two (or three) technologies:

1) ink on card;
2) new design; and
3) another previously certified livescan sensor (optionally).

The subject set should contain between five and ten people (50-100 prints), including a distribution of gender, ethnicity, age, and, if possible, various skin conditions. There is no percentage requirement for each type, just an attempt to get a broad distribution. One way to include various skin conditions is to scan dry fingers, sweaty fingers (induced by the wearing of a rubber glove), and fingers treated with an appropriate "ridge building" substance to better prepare the skin (e.g., soaking in warm water, application of hand lotion, hot sauce, or other commercially available products).[19] In addition to various stress conditions, include subject(s) with some easy-to-print fingers (e.g., wide ridges, pores easily visible, uniform contrast across the print). Individual hands or fingers may be prepared differently to obtain a wider range of skin conditions.

Personally identifying information (PII) should not be noted for any subject. Instead, each subject should be assigned a number that is used consistently as a label across the comparison collections. Documentation of the range and distribution of the above characteristics (see section 7.3) is useful, but should only be provided to the extent possible without revealing identifying information.

The vendor can collect their own inked cards (rolls and/or flats) after some experimentation and practice. An inkpad and multiple 10-print cards are available from the FBI for this purpose.

[19] Any substance used to prepare the fingers must be removed before fingerprint capture.

7.2 Stress Imagery

During livescan testing, stress images are also requested, although their assessment does not affect whether the device is recommended for certification. These images are used to observe the ability of the device to collect impressions under simulated operational conditions.

Submitted images fall into two distinct categories: those documenting the collection conditions, which are color pictures taken with a digital camera, and those from the livescanner. A stress image submission should include the following color and livescan images (from the same finger of the same individual):

1. A livescan of the reference finger captured in normal operating conditions;
2. A color picture of the simulated sunlight setup, showing the display of a light meter reading between 90,000 lux and 100,000 lux (see section 7.2.1 for guidance);
3. A livescan when the device operates under simulated sunlight conditions (see section 7.2.1 for guidance);
4. A color picture of the pad of the finger onto which an X was drawn with a black marker (see section 7.2.2 for guidance); and
5. A livescan of the finger with a drawn black X, in normal operating conditions (see section 7.2.2 for guidance).

7.2.1 Simulated Sunlight Collection Guidance

Stress imagery described in #2 and #3 here above refers to the same simulated sunlight conditions. Guidance regarding the creation of these simulated sunlight conditions is as follows:

- Use a light bulb whose emission spectrum is continuous, preferably close to that of daylight, and encompasses the entire visible spectrum;
- Safely mount the light bulb a few centimeters above the platen, as illustrated in Figure 7-1, possibly with the addition of a reflector. Illumination must be as uniform as possible over both the platen of the livescanner and the light sensor;
- It is critical to adjust the distance between the light bulb/reflector and the platen of the livescanner so that a basic light meter whose light sensor is aligned with the height of the platen reads about 100,000 lux, but not less than 90,000 lux; and
- Care should be taken to avoid burns while inserting a finger between the light bulb/reflector and the platen of the livescanner.

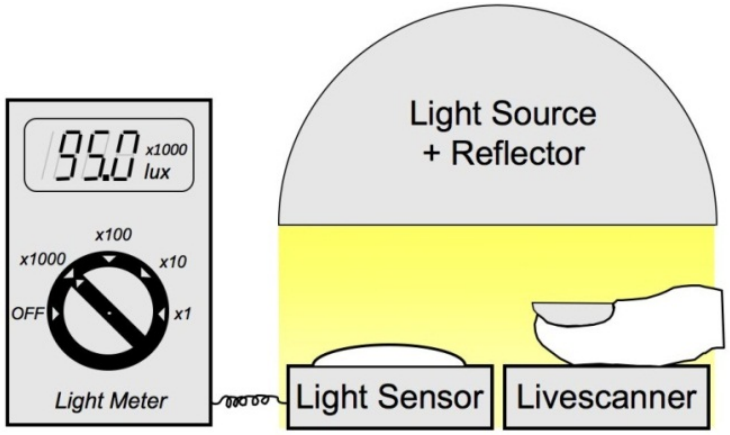

Figure 7-1. Suggested Set-up to Simulate Full Sunlight Exposure.

7.2.2 Black X Collection Guidance

Stress imagery described in #4 and #5 here above refers to the same black ink X conditions. Results are expected to vary based upon the skin reflectance of the subject and the percentage of the finger pad covered by the black ink. Guidance regarding the creation of these black ink X conditions is as follows:

- Choose a permanent black ink marker whose tip leaves a trace which is between 1 and 2.5 mm wide;
- Be sure to draw two line segments which intersect at their center, making an X shape, in the center of the pad of the finger, so that the length of each segment is about 3 times the width of the trace; and
- Obtain and send in the reference to the marker used for this experiment.

7.3 Metadata Documentation

Do not include PII, such as names, with any prints. However, because it is useful to understand the distribution of certain properties that may impact fingerprint quality, consider providing the following summary metadata information across the entire set of fingerprint captures:

- How many subjects are of each gender?
- What is the age range covered and how many subjects are young versus old?
- How many subjects have a skin color other than white?
- How many subjects have good versus poor skin condition?

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LIST OF REFERENCES

ANSI/NIST – *American National Standard for Information Systems - Data Format for the Interchange of Fingerprint, Facial, & Other Biometric Information - Part 1*, ANSI/NIST-ITL 1-2011:Update 2015, Special Publication (NIST SP) - 500-290e3, December 2015, National Institute of Standards and Technology (NIST), Gaithersburg, MD. Latest release available at http://www.nist.gov/itl/iad/ig/ansi_standard.cfm

EBTS – *Electronic Biometric Transmission Specification (EBTS)*, document number NGI-DOC-01078-10.0.6, July 2016, Federal Bureau of Investigation, CJIS Division, 1000 Custer Hollow Rd., Clarksburg, WV 26306. Latest updates available at https://www.fbibiospecs.cjis.gov/EBTS/Approved

MobileID – *Mobile ID Device Best Practice Recommendation Version 2.0*, November 2015, National Institute of Standards and Technology (NIST) Special Publication 500-280v2, available at http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.500-280v2.pdf

PIVspec – *Personal Identity Verification (PIV) Image Quality Specifications for Single Finger Capture Devices*, FBI Biometric Specifications, 10 July 2006, available at https://www.fbibiospecs.cjis.gov/Document/Get?fileName=pivspec.pdf

PIVtest – *Test Procedures for Verifying Image Quality Requirements for Personal Identity Verification (PIV) Single Finger Capture Devices*, MITRE Technical Report, MTR060170, December 2006.

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APPENDIX A

LIVESCAN TESTING NOTES

The specific design of a livescan device largely determines which targets can or cannot be successfully used. For example, for livescan devices which utilize the optical imaging principle of Frustrated Internal Reflection (FIR), also known as Total Internal Reflection (TIR), the type of two-dimensional test targets that can be successfully imaged depends on factors such as the angle of incidence of the illumination with respect to the plane of the prism surface used for fingerprint capture, and with respect to the image capture angle of the optics and sensor.

Due to a host of potentially different designs, one device might be able to image the standard Ronchi bar, uniform gray, and continuous tone sine wave targets on reflective paper or mylar substrates, while another device might require use of film transmission targets, and another device might not be able to adequately image continuous tone targets, in which case chrome-on-glass binary targets might be suitable. Regarding the latter case, continuous gray shading cannot be readily produced on chrome targets (or at least it is prohibitively expensive), so a black/white bar target would be substituted for the continuous tone sine wave target (generating CTF instead of MTF). Individual uniform reflectance chrome targets ("neutral density filters") might be used for linearity assessment or to replace the uniform gray reflection targets, or images of a blank platen might be obtained, varying the exposure time in stepped increments to effectively obtain a series of uniform gray shades.

The livescan vendor seeking certification generally needs to perform some experimentation to arrive at a suitable set of targets and procedures. The Ground Rule is to adhere as closely as possible to the target types and procedures given in Section 2 of this Test Procedures document, and stay as close as possible to the device's operational fingerprint imaging mode; changing/backing-off from these, only as is necessary. For example, it may be more convenient during testing to use an external light source, but this does not exercise the device's internal illumination as it is used in practice (spectral content, internal reflections, etc.), so external lighting should be avoided.

The vendor's proposed set of targets and test procedures should be communicated to the FBI (see point-of-contact in Section 1), for comment and possible recommended changes, with the goal in mind of obtaining a mutually agreed upon set of targets and procedures that comprehensively serve the purpose of the testing. If a set of procedures are agreed upon for one livescan model and, later, another model with the same basic design comes along (from same vendor), the same set of test procedures can most likely be applied.

Some Additional Points:

- In some cases it may be necessary to apply a wetting agent to the targets, i.e. an index-of-refraction matching fluid, or "liquid gate". If a wetted sine wave target is used, it may be necessary to recalibrate the target's sine wave modulations and gray patch density values in its wet state. Liquid-gating is obviously a messy process that is prone to increased variability of results, with the possibility of increased nonuniformities and emulsion swelling which may distort the target.

- Platen Coating (Membrane): if the livescan device uses a membrane over the glass prism, usual purpose being to obtain better finger ridge contact to the prism surface, then testing must be performed with the membrane in place. Live scanner certification is "with membrane", "without membrane", or "with and without membrane" (the latter requires two test sets).

- Roll Tracking Mechanism: The geometric integrity of a roll tracking mechanism is not normally tested directly; i.e., the Ronchi bar test is normally performed in a static, single image capture mode. However, roll tracking that has significant problems will likely produce anomalies or artifacts in the roll fingerprint scans that are required to be submitted; these will be assessed for such problems.

APPENDIX B

COMMERCIAL SOURCES FOR TARGETS

This Appendix lists manufacturers and/or resellers of some of the test targets that could be used in IQS certification. Table B-1 and the accompanying list of target vendors is NOT all-inclusive and it is not intended to endorse one product over a competitor's product. There may be other viable target types and commercial sources not listed here.

Table B-1. Test Targets

Target Model	Type	Target Frequency Range (cy/mm)	Target Dimensions (millimeters)	Target Substrate Material
M13-60-1X	sine wave	0.188 to 12	48 x 70	photo paper
M15-60	sine wave	0.25 to 20	48 x 70	photo paper
M13-60-1/2X	sine wave	0.25 to 12	24 x 35	photo paper
M-6	sine wave	0.375 to 80	46 x 70	film
M-7	sine wave	0.75 to 128	22 x 30	film
TC-12-1	bar	1 to 10	38 x 38	black chrome on opel
____	Ronchi	1.0 cy/mm	100 x 100 typical	reflective mylar, chrome-on-glass
Munsell N9, N3	uniform gray	____	216 x 279 typical	coated paper
IT8	step tablet	____	156 x 104 typical	photo paper, film

Note: Due to the lack of 7 and 9 cy/mm bar patterns, the T-90 bar target is no longer acceptable. The TC-12-1 is a possible alternative.

Commercial Target Sources:

Sine wave Bar Ronchi SIQT Step Tablet Precision Scale	Applied Image, Inc. 1653 East Main Street Rochester, NY 14609 Telephone: (585) 482-0300 http://www.appliedimage.com http://www.sinepatterns.com (Includes Sine Patterns, LLC as manufacturer of sine wave targets.)
Bar Ronchi SIQT Step Tablet	Precision Optical Imaging, Inc. 62 Honeoye Falls 5 Pts Road Rush, NY 14543 Telephone: (585) 533-9133 http://www.precisionopticalimaging.com
Bar Sine wave Ronchi	Edmund Scientific Corp. 101 East Gloucester Pike Barrington, NJ 08007 Telephone: (800) 363-1992 http://www.edmundoptics.com
Bar Sine wave Ronchi	JML Optical Industries, Inc. 820 Linden Avenue Rochester, New York 14625-2710 Telephone: (585) 248-8900 http://www.jmloptical.com
Munsell Gray (N9, N3) Step Tablet	X-Rite, Inc. (Munsell Color Lab) 4300 44th Street SE Grand Rapids, MI 49512 Telephone: (800) 622-2384 http://www.xrite.com 8.5” x 11” matte surface: N9 - cat.#22408 N3 - cat.#22384
Bar Ronchi Step Tablet	Image Engineering Augustinusstrasse 9d 50226 Frechen, Germany Telephone: 49 (0) 22 34 - 91 21 41 http://www.image-engineering.de

Precision Scale Bar	Gurley Precision Instruments, Inc. 514 Fulton Street Troy, NY 12181 Telephone: (800) 759-1844 http://www.gpi-optics.com/opto.htm

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APPENDIX C

GEOMETRIC ACCURACY MEASUREMENT

Ronchi Target Accuracy:

The geometric accuracy requirements, test methodology, and compliance verification for a scanner are consistent with use of a 1.0 cy/mm Ronchi bar target that has less than a 0.25 percent error in bar center-to-bar center spacing. This error tolerance is readily available from chrome-on-glass Ronchi targets, and can also be obtained from Ronchi targets on a flexible mylar substrate. With this target error tolerance, it is not necessary to incorporate target calibration data into the IQS compliance measurement computations.

Even if the Ronchi target error is slightly larger than 0.25 percent, use of that target without calibration data is acceptable as long as the scanner still meets the geometric accuracy requirements. The reasoning is that it is highly improbable that the target errors would be exactly in-phase with the scanner geometric errors, and of opposite sign, both of which would be required for scanner errors to cancel target errors. If the geometric accuracy requirement is still met with this target, it simply indicates that the combination of target errors plus scanner errors are relatively small.

A printer uses a digital Ronchi bar target which has zero error when one period on the target is exactly equal to a whole number of pixels. When printed at 500 ppi, a digital Ronchi bar target with a period of exactly 18 pixels corresponds to a frequency on the print of 1.0936 cy/mm, or a period of 0.0360 inches.

The following geometric accuracy assessment description is principally for a scanner; where printer assessment differs, it is so noted. This assessment procedure for scanners and printers is implemented in the *geo* program, which is on the IQS Test Tools CD.

Measurement Definitions and Approach:

1) The target is scanned such that the bars are aligned parallel to one of the two axes of the scanner's detector array (detector rows or columns), to within 0.5 degrees, which then defines the direction, vertical or horizontal.

2) Common terminology used in this Appendix is given in the following and is illustrated in Figure C-1.

a) A **measurement strip** is a single, continuous strip in the target image, across multiple parallel Ronchi bars, within which scanner resolution and geometric

accuracy measurements are taken; e.g., 10 measurement strips are depicted in the horizontal bar Ronchi target "A" in Figure 2-2.

b) A **bar** is an individual black stripe of the Ronchi target.

c) A **bar segment** is the portion of a bar that is contained in a measurement strip.

d) An **edge line** of a bar segment is the line at the boundary of the white background and the black bar and is calculated from image data for that bar segment. There are two edge lines for each bar segment.

d) The **center line** of a bar segment is the line running down the center of a bar, parallel to the two edge lines for that bar segment.

e) The **center point** of a bar segment is the mid-point of the bar segment's center line.

f) In the following discussion references to *row*, *top*, and *bottom* pertain to horizontal bars, with measurements in the vertical direction. The same test methodology is applied to vertical bars, with measurements in the horizontal direction, by substituting the terms *column*, *left*, and *right*, respectively.

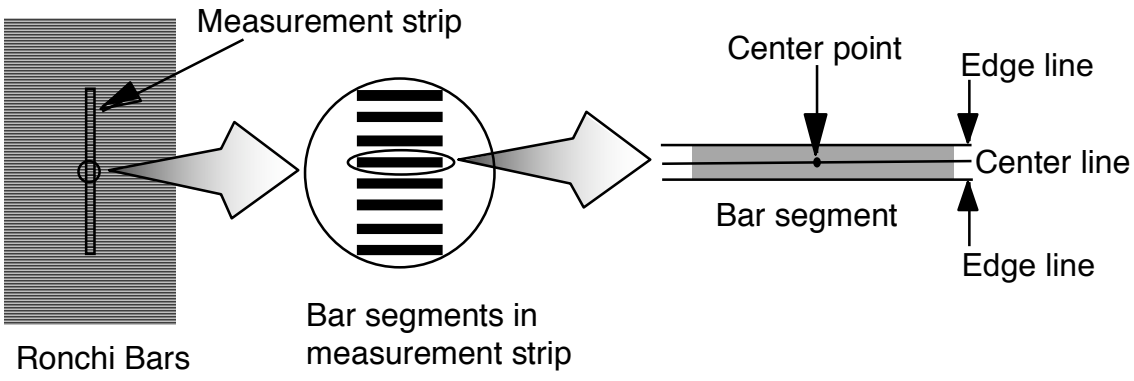


Figure C-1. Illustration of Definitions Used For Ronchi Target Computations

3) The center line of a bar segment represents the line that is midway between the two edge lines of that bar segment. All distances are measured between the center lines of bars, because the more accurate tolerance for the scanner test Ronchi target is in terms of bar center-to-bar center distance. Center lines are not calculated directly, however, they are based on measurements of bar segment edge line locations. The steps for calculating a bar segment's edge lines are as follows:

a) The edge locations of each bar segment are calculated every fifth pixel along each bar edge, for a distance of 0.25 inches for scanner measurements, yielding 26 points for each edge for a 500 ppi scanner and 52 points for each edge for a 1000 ppi scanner. For printer assessment (500 ppi print scanned at 1000 ppi) a measurement strip distance of 0.20 inches is used, yielding 41 points for each edge. Edge locations are determined using the super-resolution edge detection method presented in Seitz[20], Section 3: "Subpixel Resolution Edge Detection", to locate edges of transition from black to white and white to black. This method calculates the location of a point on an edge within 2^{2-N} of the true position, after N iterations of a bisection method. In the *geo* program, each iteration is applied to two different edge locations, x, and the process determines which of the two locations yields the maximum value of the function r(x). The inferior edge location, as indicated by a smaller r() value, is replaced by the midpoint (bisection) of the two previous locations, and this process is then repeated with these two locations. In order to overcome the possibility of dust or scratches altering the expected edge locations, the initial edge range is set quite large, using x values from -8 to 8. Because this range is so large, the initial search reduces the edge range by only 1/8, over 32 iterations, which avoids missing the actual edge location in this broad expanse. Once the range has been reduced in this manner, then the normal Seitz bisection proceeds. To achieve (and probably exceed) the desired 0.05 percent accuracy, N is set equal to 16.
The value of f_i is the difference between consecutive image pixel values I_i and I_{i-1}.

$$f_i = I_i - I_{i-1} \tag{C-1}$$

$$r(x) = \sum_{i=-4}^{4} |f_i| e^{-a^2(x-i)^2} \quad , a = \frac{\pi}{4} \tag{C-2}$$

b) Once the point positions along an edge of a bar segment have been determined, the best fit line is calculated using these points in a linear, least squares regression to determine the edge line. This line fitting is done separately for each edge of each bar segment. The application of this line fitting requires that the y values

[20] *Optical Superresolution using Solid-State Cameras and Digital Signal Processing, P*. Seitz, July, 1988, Optical Engineering, Vol. 27, No.7, pp. 535-540.

correspond to the row positions for the horizontal Ronchi bars, and the y values correspond to the column positions for the vertical Ronchi bars. Figure C-2 shows an example of the 26 points along each edge of a bar, within a measurement strip, that are used to determine the center line or center point of a bar segment scanned at 500 ppi. The combination of the subpixel resolution method and linear, least squares regression allows the position of the bar segment edge line to be accurately determined to within a small fraction of a pixel, and this combination is robust in the presence of dust and scratches on the target.

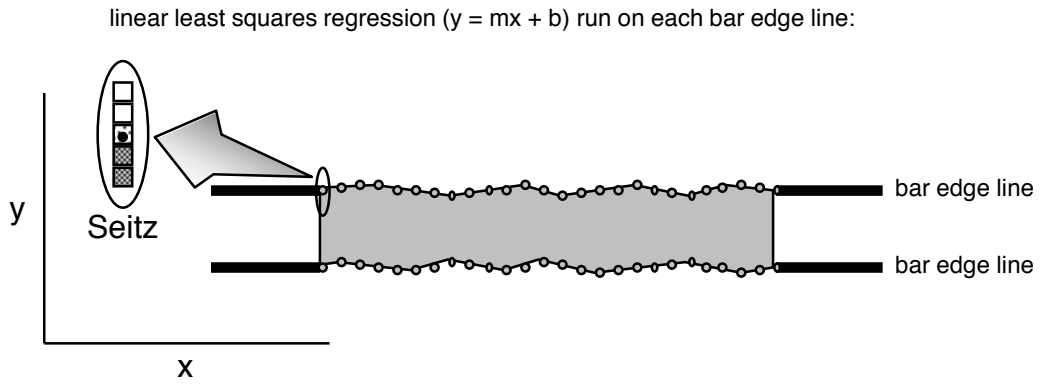


Figure C-2. Example of Calculating the Edge Lines of a Bar Segment

4) The distance between the centers of two bar segments in the same measurement strip is effectively calculated as the perpendicular distance between the center point of one bar segment and the center line of the other bar segment. As defined in equation C-3 and illustrated in Figure C-3, the distance is actually computed from the bar edge slopes (m) and intercepts (b) of the bar edges, and the center points (x_c) of the bars.

$$D = \left|\cos(\alpha)(y_0 - y_1)\right| \tag{C-3}$$

where,

$$\alpha = \frac{\arctan(m_{10}) + \arctan(m_{11})}{2}$$

$$y_0 = \frac{(m_{00}+m_{01})x_c + (b_{00} + b_{01})}{2}$$

$$y_1 = \frac{(m_{10}+m_{11})x_c + (b_{10} + b_{11})}{2}$$

x_c is the middle row (column) of the measurement strip

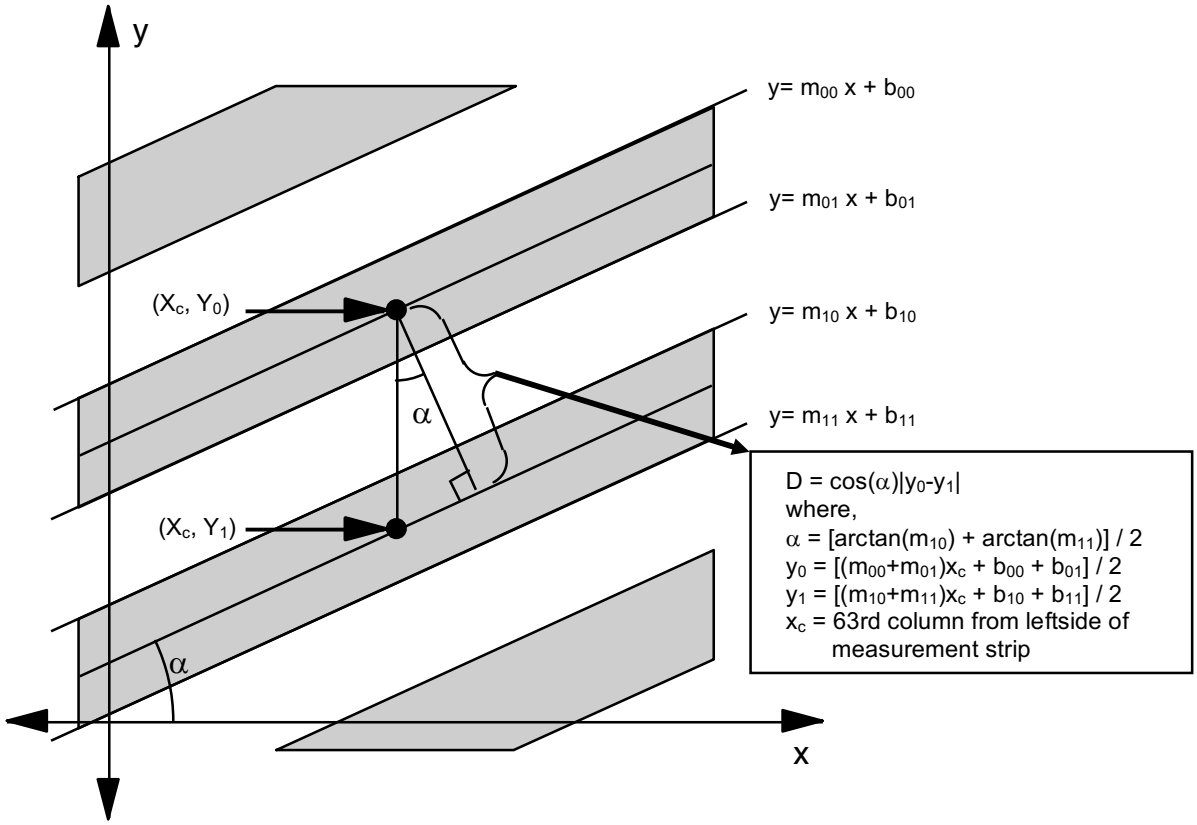


Figure C-3. The Distance Between a Point and a Line

The center point of a bar's centerline is located X columns in from the left edge of the bar segment, where X = 63 for 500 ppi scans and X = 126 for 1000 ppi scans (for scanner assessment). Figure C-4 illustrates the distance measurement between the centers of two bar segments, for a target scanned at 500 ppi.

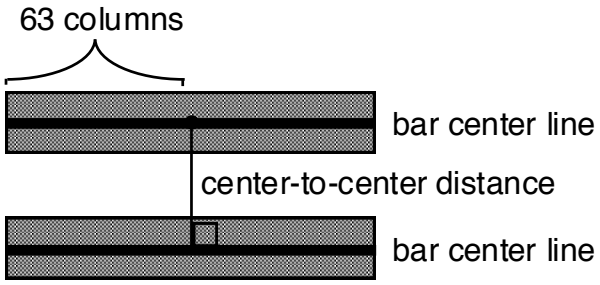


Figure C-4. The Distance Between Two Bar Centers is the "One Bar Distance Measurement"

5) As illustrated in Figure C-5, the first bar segment used in all measurements of a given measurement strip is the topmost full-width bar in that strip, and the last bar segment used is the bottommost full-width bar in that strip.

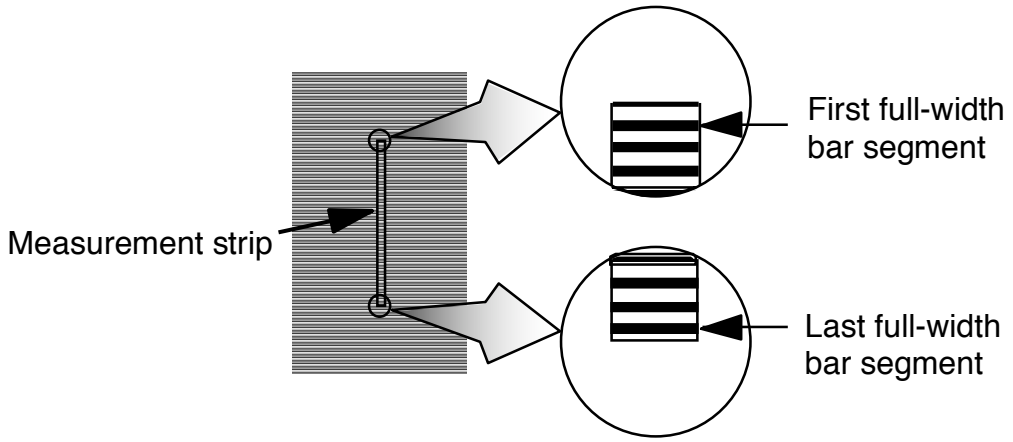


Figure C-5. Examples of First and Last Full-Width Bar Segments in a Measurement Strip

Measurements Performed:

For each measurement strip, the scanner resolution is first measured, both to verify compliance with the pixels per inch requirement and to establish a pixels per inch value that can be used to convert subsequent geometric accuracy measurements to inches. Next, measurements are made to test the across-bar geometric accuracy over a short distance of one Ronchi bar cycle; then, measurements are made to test the across-bar geometric accuracy over a longer distance of 6 Ronchi bar cycles.

The calculations necessary for verification of compliance with the resolution and geometric accuracy requirements can be performed by the *geo* software, which is on the IQS Test Tools CD. The input data file needed to run *geo* can be created by the *creategeofile* software. The output of *geo* includes the across-bar results for each individual 1-bar and 6-bar sample measurement (distance error and location), the computed ppi for each 6-bar sample measurement, the along-bar distortion test results, and summary results for all 1-bar and 6-bar measurements in each measurement direction (vertical and/or horizontal). The *viewgeo* software accepts *geo*'s output file to create a type of error map image, which is a convenient way to visualize the locations and magnitudes of the geometric errors; e.g., highlight periodicities in the errors.

Resolution Measurements

The first set of measurements establishes the scanner resolution in the row and column directions. Individual scanner resolution measurements are taken over every six bar distance. Scanner resolution in pixels per inch (ppi) is calculated as the number of pixels between the specified bar centers in a given measurement strip, multiplied by a conversion factor, as given in equation C-4. The average resolution is then calculated for each measurement strip.

$$\text{ppi} = K \times (\text{width of 6 cycles in pixels}) \qquad \text{(C-4)}$$

where,

$$K = \frac{\text{mm/inch}}{\text{number of cycles}} = \frac{25.4}{6} = 4.233$$

Specific to printer assessment: printer target version A8 contains Ronchi bars that are 0.260 inches long when printed at 500 ppi. When a scanned print is input to the *geo* software, a 0.200 inch section of this 0.260 inch length is used for each measurement strip. Therefore, there is only one measurement strip in the 7 inch vertical bars Ronchi segment and one in the 4.75 inch horizontal bars Ronchi segment. The average ppi is the average taken over the entire strip length and this average ppi is then used in each individual 6-bar distance error assessment within that strip.

Across-Bars Geometric Accuracy Measurements

The first set of measurements for geometric accuracy tests the short distance accuracy, i.e., less than 0.07 inch distance. For each measurement strip, distance measurements are made between the centers of each pair of adjacent bars, starting with the topmost complete bar segment. Each distance measurement is converted from pixels to inches by dividing the distance measurement (in pixels) by the previously computed average resolution for the given directional measurement strip.

The second set of measurements tests the geometric accuracy for distances in the 0.07 to 1.5 inch range, by measuring the distance between six bars (6 bar cycles), which is a target distance of 0.23622 inches for scanner assessment using 1.0 cy/mm Ronchi target bars, or 0.21600 inches for printer assessment using 1.0936 cy/mm Ronchi target bars. For every sixth bar in each measurement strip, distance measurements are made between the centers of bar pairs having five bars between them, starting with the topmost complete bar segment. Each distance measurement is converted from pixels to inches by dividing the distance measurement (in pixels) by the previously computed average resolution for the given directional measurement strip.

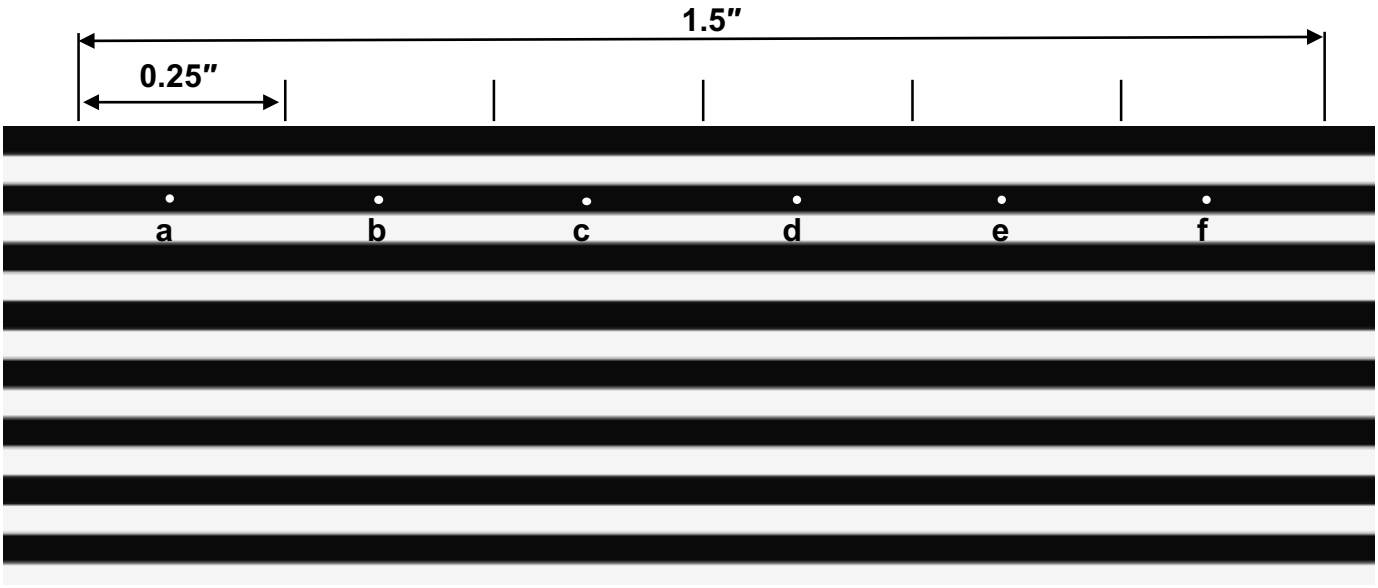
Along-Bar Geometric Accuracy Measurement (Distortion Measurement)

The bar center locations established for across-bar geometric accuracy assessment form the basis of assessments for along-bar geometric accuracy assessments, i.e., distortion assessments. As illustrated in Figure C-6, since the bar center locations at a, b, c, d, e, f are known, from the previously computed across-bar measurements, then it only remains to determine the largest difference in center locations over a 1.5 inch bar length and compare it to the allowable maximum. Some additional measurement aspects:

- All comparable along-bar measurements are made within the image area corresponding to a single, continuous Ronchi target.

- The along-bar measurements are applied to every bar.

- The difference in fractional rows between two bar centers is converted to inches by dividing by the average ppi of the two corresponding measurement strips.



meas. strip	avg. ppi	bar center location	at row
1	501.3	a	10.0
2	500.2	b	11.3
3	498.5	c	14.2
4	500.8	d	16.2
5	502.2	e	15.3
6	504.1	f	14.5

largest vertical difference over 1.5″ horizontal distance:

[(row$_d$ @ 16.2) - (row$_a$ @ 10.0)] / 501.05 = 0.01237″

0.01237″ meets spec, since it is less than 0.016″

Figure C-6. Example of Along-Bar Distortion Measurement

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APPENDIX D

CONSTRUCTION OF STRATIFIED TEST CARD SET

This Appendix describes the procedure used to construct a stratified master card set[21] from the FBI's Fingerprint Card Master File (FCMF). The same procedure could be used on other card sets that contain a range of card types, i.e., light, medium, and dark-inked cards[22].

Scanners are evaluated with a standard test set of fingerprint cards representing the range of quality found in the master file. However, only a very low percentage of the FCMF cards exhibit fewer than 128 gray-levels, so a straightforward sample test would require a relatively large number of test cards to adequately test the scanner's capability to handle such low contrast cards. A stratified sampling protocol, although more complex, overcomes this problem; i.e., stratified sampling avoids the necessity for a very large number of test cards. A stratified sample provides much better discrimination by focusing sample resources in the areas of interest.

Stratification of a 100 card set from the FCMF is based on the gray scale range[23] of finger three (right middle finger); strata definitions and sample sizes are given in Table D-1.

Table D-1. Strata, Gray Scale Ranges, Sample Sizes for FCMF 100 Card Test Set

Stratum	Finger 3 Gray Scale Range	Number of Cards
1	1 to 127	40
2	128 to 199	40
3	200 to 256	20

[21] Reference for generating stratified sample set: *Survey Sampling*, L. Kish, 1965, Wiley, NY, chapter 3: "Stratified Sampling", pp. 75-112.

[22] In July 2015, a new stratified 50 card test set was constructed as the old card sets were retired. Selection of the new 50 card set from a 480 card supply of deceased cards was performed by mimicking the retired set's gray-level range and contrast distributions. The gray-level range was measured as the 90^{th} - 10^{th} percentile gray-level difference. Both gray-level range and contrast metrics were calculated using the MTF grayfinger software code.

[23] In this Appendix it is the number of gray-levels that is being dealt with, which ranges from 1 to 256; terminology used in other sections of this document refers to a pixel's gray-level value, which ranges from 0 to 255.

The distribution of gray scale ranges for all 10 rolled fingerprints[24] for the cards in each of the three stratums is shown in Table D-2. For example, for the 40 cards in stratum 1 (400 rollprints) the vast majority of the individual finger images have less than 128 gray-levels, which is the same range exhibited by all 40 finger 3 images. However, 75 of the (non-finger 3) finger images from these 40 cards do contain between 128 and 199 gray-levels. Note that these gray-level distributions are the result of card scan data gathered from a scanner set-up with linear response and no adaptive gray-level processing. When some form of adaptive gray-level processing is applied, one would expect an increase in number of gray-levels in each stratum; e.g., many of the 325 samples in stratum 1, gray range 1 to 127, would shift to the two higher gray ranges.

The weight, W_h, associated with stratum h, is the proportion of FCMF cards that fall within that stratum. These weights were derived from gray scale measurements made on 4,685 cards randomly selected from the total FCMF population of approximately 30 million cards. The W_h weights for the three stratums (h=1,2,3) are given by:

W_1 = (number of cards for which finger 3 has 1 to 127 gray-levels) ÷ 4685
W_2 = (number of cards for which finger 3 has 128 to 199 gray-levels) ÷ 4685
W_3 = (number of cards for which finger 3 has 200 to 256 gray-levels) ÷ 4685

Table D-2. Gray Scale Ranges in 100 Card FCMF Test Set

Stratum (h)	Range: 1 to 127	Range: 128 to 199	Range: 200 to 256	Weight (W_h)
1	325	75	0	0.0314
2	3	385	12	0.9628
3	0	64	136	0.0058

If the scanner under test is to be primarily used to scan cards from another master file of fingerprint cards, and if it is known or assumed that this other master file has gray scale characteristics significantly different from the FBI's FCMF, then a stratified random sample set of test cards can be assembled from this other master file. To accomplish this, a table analogous to Table D-2 is constructed, resulting in Table D-3. In Table D-3, the parameter value $n_{1,c}$ is the number of subimages in the first stratum that exhibit a dynamic range of 1 to 127 gray-levels. The parameter value $n_{3,u}$ is the number of subimages in the

[24] The proportions of the various gray scale ranges in the four plain impression fingerprint blocks, which were not used in constructing Table D-2, typically correspond to the proportions in the ten rolled fingerprint blocks.

third stratum that exhibit a dynamic range of 200 to 256 gray-levels, and similarly for the other cases.

Table D-3. Gray Scale Ranges for Card Test Set

Stratum (h)	Range c: 1 to 127 Gray-Levels	Range s: 128 to 199 Gray-Levels	Range u: 200 to 256 Gray-Levels	Weight (W_h)
1	$n_{1,c}$	$n_{1,s}$	$n_{1,u}$	W_1
2	$n_{2,c}$	$n_{2,s}$	$n_{2,u}$	W_2
3	$n_{3,c}$	$n_{3,s}$	$n_{3,u}$	W_3

The proportion of subimages that have less than 128 gray-levels is equal to the weighted average of within strata estimates; i.e., each stratum represents its share of the population. This weighted average, A_c, is given by equation D-1:

$$A_c = \sum_{h=1}^{3} \frac{W_h n_{h,c}}{n_h} = (W_1 n_{1,c} \div n_1) + (W_2 n_{2,c} \div n_2) + (W_3 n_{3,c} \div n_3) \qquad \text{(D-1)}$$

where n_h is the total number of subimages in stratum h

The weighted average for the proportion of subimages which have 200 to 256 gray-levels, denoted A_u, is similarly defined in equation D-2:

$$A_u = \sum_{h=1}^{3} \frac{W_h n_{h,u}}{n_h} \qquad \text{(D-2)}$$

The specification requires that at least 99% of the strata-weighted images have 128 or more gray-levels, i.e.;

$$(1 - A_c) \geq 0.99$$

and at least 80% of the strata-weighted images have 200 or more gray-levels, i.e.;

$$A_u > 0.80$$

where A_c and A_u are the strata-weighted averages for the scanner output subimages.

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GLOSSARY

ADF	Automatic Document Feeder
AFIS	Automated Fingerprint Identification System
AIIM	Association for Information and Image Management
AMP	amputated or bandaged
ANSI	American National Standards Institute
avg	average
bpp	bits per pixel
CD	Compact Disk
CJIS	Criminal Justice Information Services
CTF	Contrast Transfer Function
cm	centimeter
cy/mm	cycles per millimeter
DFT	Discrete Fourier Transform
EBTS	Electronic Biometrics Transmission Specification
FAP	Fingerprint Acquisition Profile
FBI	Federal Bureau of Investigation
FCMF	Fingerprint Card Master File
FICO	Fingerprint Image Capture Operations
FIPS	Federal Information Processing Standard
FIR	Frustrated (Total) Internal Reflection
FP	Fingerprint
H	Horizontal
HW	Hardware
IAFIS	Integrated Automated Fingerprint Identification System
ID	Identification
Inc	Incorporated
IQS	Image Quality Specification
ISO	International Organization for Standardization
JPEG	Joint Photographic Experts Group
LLC	Limited Liability Corporation
mm	millimeter
MTF	Modulation Transfer Function
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
PGM	Portable GrayMap
PII	Personally Identifiable Information
PIV	Personal Identity Verification
ppi	pixels per inch
SAP	Subject Acquisition Profile
SIQT	Scanner Image Quality Test (target)
SNR	Signal-to-Noise Ratio

spec	specification
SW	Software
TGT	digital target for printer testing
TIFF	Tagged Image File Format
V	Vertical
VAR	Value-Added Reseller
WSQ	Wavelet Scalar Quantization