Personal Identity Verification (PIV)

IMAGE QUALITY SPECIFICATIONS FOR SINGLE FINGER CAPTURE DEVICES

1.0 SCOPE AND PURPOSE

These specifications apply to fingerprint capture devices which scan and capture at least a single fingerprint in digital, softcopy form. These specifications provide criteria for insuring that the image quality of such devices is sufficient for the intended applications; a primary application is to support subject authentication via one-to-one fingerprint matching in the United States government's Personal Identity Verification program [PIV].

The fingerprint capture device must be capable of producing images which exhibit good geometric fidelity, sharpness, detail rendition, gray-level uniformity, and gray-level dynamic range, with low noise characteristics. The images must be true representations of the input fingerprints, without creating any significant artifacts, anomalies, false detail, or cosmetic image restoration effects. The fingerprint capture device is expected to generate good quality finger images for a very high percentage of the user population, across the full range of environmental variations seen in the intended applications.

2.0 REQUIREMENTS

The image quality requirements have associated test procedures which are described elsewhere [TestPro]. These test procedures will be used by the FBI for certification of these devices; they may also be used in acceptance testing, and in performance capability demonstrations, as an indication of capability-to-perform.

Verification of compliance of the fingerprint capture device with the requirements shall primarily be 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 [Verify]. The FBI has test analysis software available for this purpose.

The device shall be tested to meet the requirements in its normal-operating-mode, with the following possible exceptions:

1) If the device has a strong anti-spoofing feature, of a type whereby only live fingerprints will produce an image, then this feature needs to be switched-off or bypassed in the target test mode of operation.

2) If the device's normal output is not a monochrome gray scale image, e.g., it is a binary image, minutia feature set, color image, etc., then the monochrome gray scale image needs to be accessed and output in the test mode of operation.

3) Other normal-operating-mode features of the device similar/comparable/analogous to (1) and (2) may need to be disengaged.

Table 1 gives some of the basic requirements for the single finger capture device.

Table 1. Basic Requirements

Parameter	Requirement
Capture Size	≥ 12.8 mm wide by ≥ 16.5 mm high
True Optical or Native Resolution (Nyquist frequency)	≥ 500 ppi in sensor detector row and column directions
Resolution Scale	490 ppi to 510 ppi in sensor detector row and column directions
Image Type	Capability to output monochrome image at 8 bits per pixel, 256 gray-levels (prior to any compression)

mm = millimeters
ppi = pixels per inch
≥ greater than or equal to

2.1 GEOMETRIC ACCURACY

Requirement #1 (across-bar)
A multiple, parallel bar target with a one cy/mm frequency is captured in vertical bar and horizontal bar orientations. The absolute value of the difference between the actual distance across parallel target bars, and the corresponding distance measured in the image, shall not exceed the following values, for at least 99% of the tested cases in each of the two orthogonal directions.

$$D \leq 0.0013, \quad \text{for } 0.00 < X \leq 0.07$$

$$D \leq 0.018X, \quad \text{for } 0.07 \leq X \leq 1.50$$

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

Requirement #2 (along-bar):
A multiple, parallel bar target with a one cy/mm frequency is captured in vertical bar and horizontal bar orientations. The maximum difference between the horizontal direction locations (for vertical bar) or vertical direction locations (for horizontal bar), of any two points separated by up to 1.5 inches along a single bar's length, shall be less than 0.027 inches for at least 99% of the tested cases in the given direction.

Requirements #1 and #2 may be verified by the *Inspection Method*[1] instead of the *Test Method*, if the fingerprint capture device has all of the following characteristics, and adequate documentation for these characteristics is supplied:
- Construction of a suitable 1 cy/mm Ronchi target that will produce measurable images with the capture device requires extraordinary effort and resources.
- The sensor is a two-dimensional staring array (area array) on a plane (not curved) surface.
- There is no movement of device components, nor purposeful movement of the finger, during finger image capture.
- There is no device hardware component (e.g., a lens or prism) between the finger and the sensor, with the possible exception of a membrane on the sensor surface which, if present, does not alter the geometry of the imaged finger.
- Any signal processing applied to the captured finger image does not alter the geometry of the captured finger image.

Background:
The phrase: *multiple, parallel bar target* refers to a Ronchi target, which consists of an equal-width bar and space square wave pattern at 1.0 cy/mm, with high contrast ratio and fine edge definition.

Across-bar geometric accuracy is measured across the imaged Ronchi target bars, which cover the total image capture area. The requirement corresponds to a positional accuracy of ± 1.8% for distances between 0.07 and 1.5 inches, and a constant ± 0.0013 inches (2/3 pixel) for distances less than or equal to 0.07 inches. These across-bar measurements are also used to verify compliance with the device's resolution scale tolerance requirement given in Table 1.

Along-bar geometric accuracy is measured along the length of an individual Ronchi bar in the image. 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 bar's length, is compared to the maximum allowable difference requirement (analogously for vertical bar). This requirement is to ensure that pincushion, barrel, or other types of distortion are not too large, over the area of a single fingerprint.

[1] *Inspection Method* - verification by review of descriptive documentation, without the use of laboratory equipment or procedures [Verify].

2.2 SPATIAL FREQUENCY RESPONSE (SFR)

Requirements:
The spatial frequency response shall normally be measured by either using a bi-tonal, high contrast bar target, which results in the device's Contrast Transfer Function (CTF), or by using a continuous-tone sine wave target, which results in the device's Modulation Transfer Function (MTF). If the device cannot use a bar target or sine wave target, i.e., a useable/measurable image cannot be produced with one of these targets, then an edge target can be used to measure the MTF[2].

The CTF or MTF shall meet or exceed the minimum modulation values defined in equation 1 (for CTF) or equation 2 (for MTF), over the frequency range of 1.0 to 10.0 cy/mm, in both the detector row and detector column directions, and over any region of the total capture area. Table 2 gives the minimum CTF and MTF modulation values at nominal test frequencies. None of the CTF or MTF modulation values in the 1.0 to 10.0 cy/mm range shall exceed 1.12, and the target image shall not exhibit any significant amount of aliasing in that range.

Equation 1:

$$CTF = -5.71711E-05*f^4 + 1.43781E-03*f^3 - 8.94631E-03*f^2 - 8.05399E-02*f + 1.00838$$

Equation 2:

$$MTF = -2.80874E-04*f^3 + 1.06255E-02*f^2 - 1.67473E-01*f + 1.02829$$

(equations valid for f = 1.0 to f = 10.0 cy/mm)

Table 2. CTF and MTF Requirements at Nominal Test Frequencies

Frequency (f) in cy/mm at object plane	Minimum CTF Modulation when using Bar Target	Minimum MTF Modulation when using Sine Wave or Edge Target
1.0	0.920	0.871
2.0	0.822	0.734
3.0	0.720	0.614
4.0	0.620	0.510
5.0	0.526	0.421
6.0	0.440	0.345
7.0	0.362	0.280
8.0	0.293	0.225
9.0	0.232	0.177
10.0	0.174	0.135

[2] If it is conclusively shown that neither a sine wave target, nor bar target, nor edge target can be used in a particular device, other methods for SFR measurement may be considered.

Background:

The 1.12 upper limit for modulation is to discourage image processing that produces excessive edge sharpening, which can add false detail to an image and/or excessive noise.

Aliasing can be investigated quantitatively (e.g., Fourier analysis) and, for sine wave or bar images, from visual observation of the softcopy-displayed images. It is recognized and accepted that some amount of aliasing-due-to-decimation is often unavoidable at the higher frequencies, but aliasing-due-to-upscaling is not acceptable at any frequency within the required Nyquist limit.

The target can be fabricated of any material and on any substrate suitable for measurement with the given device, working in reflective, transmissive, or other signal transfer mode, and in either two-dimensions or three-dimensions.

If the relation between output gray-level and input signal level is nonlinear, i.e., the device's input/output response is nonlinear, then this needs to be appropriately accounted for in the computations for MTF or CTF. [MTF and CTF are strictly defined only for a linear or linearized system.]

It is not required that the CTF or MTF be obtained at the exact frequencies listed in Table 2; however, the CTF or MTF does need to cover the listed frequency range, and contain frequencies close to each of the listed frequencies.

Sine Wave Target - Commercially manufactured sine wave targets commonly contain a calibrated step tablet for measurement of the device's input/output response, and the target sine wave modulation values are also supplied, which are used to normalize the device output modulation values to arrive at the device MTF.

Bar Target - The bar target must contain an adequate number of parallel bars at each spatial frequency, i.e., enough bars to help ensure capture of optimum phasing between the target and the device's sensor, and to aid investigation of potential aliasing. The bar target must also contain a very low frequency component (less than 0.3 cy/mm), such as a single large bar, with the same density as the other bars (used for normalization).

If the device has a nonlinear response then a procedure analogous to that used for sine wave processing will have to be used to establish the effective bar image modulation values in target space [TestPro].

The spatial frequency response of the bar target itself may not be known. In such a case, the device output bar modulation values (in image space or, if nonlinear response, in target space) are normalized by the near-zero frequency bar output modulation value, resulting in an acceptable measure of the device CTF.

Edge Target - The computation of MTF from an imaged edge target follows the relevant ISO standard [Edge]. The target edge is oriented at an angle of 5.2 degrees, alternately with respect

to the sensor row and column directions. If the device has a nonlinear response then the nonlinearity needs to be measured and taken into account in the computations. The computed output modulation values are normalized to 1.0 at zero frequency (by dividing by the area of the line spread function), resulting in an acceptable measure of the device MTF. If the spatial frequency response of the target edge is known, then a further division by that response function is performed to obtain a more exact measure of the device MTF. The edge target should contain at least two fiducial marks from which the image scale in the across-the-edge direction can be measured, in pixels per inch.

2.3 GRAY-LEVEL UNIFORMITY

Requirement #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 the capture area, shall not differ by more than 1.5 gray-levels when scanning a uniform dark gray target, and shall not differ by more than 3.0 gray-levels when scanning a uniform light gray target.

Requirement #2 - pixel to pixel uniformity:
For at least 99.0% of all pixels within every independent 0.25 by 0.25 inch area located within the capture area, no individual pixel's gray-level shall vary from the average by more than 8.0 gray-levels when scanning a uniform dark gray target, and no individual pixel's gray-level shall vary from the average by more than 22.0 gray-levels when scanning a uniform light gray target.

Requirement #3- small area uniformity:
For every two independent 0.25 by 0.25 inch areas located within the capture area, the average gray-levels of the two areas shall not differ by more than 3.0 gray-levels when scanning a uniform dark gray target, and shall not differ by more than 12.0 gray-levels when scanning a uniform light gray target.

Requirement #4 - Noise
The noise level, measured as the standard deviation of gray-levels, shall be less than 3.5 in every independent 0.25 by 0.25 inch area located within the capture area, when scanning a uniform dark gray target and a uniform light gray target.

Background:
Any suitable uniform light gray target and dark gray target may be used for measuring requirements #1 to #4, including a pseudo-target. [The pseudo-target concept images the blank capture area with, for example, the exposure time turned up or down, producing a uniform light gray or dark gray image, respectively.] Each target needs to cover the entire capture area.

The device is set up such that the light average gray-level is at least 4 gray-levels below the device's highest obtainable gray-level when capturing fingerprints, and the dark average gray-level is at least 4 gray-levels above the device's lowest obtainable gray-level when capturing fingerprints. This avoids possible saturation levels and levels that are outside the range obtained in actual fingerprint captures.

2.4 FINGERPRINT IMAGE QUALITY

The fingerprint capture device shall provide fingerprint image quality which is high enough to support the intended applications; a primary application is to support subject authentication via one-to-one fingerprint matching.

The image quality will be assessed with respect to the following requirements, by applying visual and quantitative measurements to test livescans captured on the given device. These test livescans shall consist of:

- a set of 20 fingers, nominally acquired from 10 different subjects and 2 fingers per subject (preferably left/right index finger) and,

- a set of 5 index finger repeat captures from the same hand of a single subject.

All of these test livescans shall be supplied for assessment in 8 bits per pixel, monochrome (grayscale), uncompressed format (and have never been lossy-compressed).

Requirement #1 - Fingerprint Gray Range:
At least 80.0 % of the captured individual fingerprint images shall have a gray-scale dynamic range of at least 150 gray-levels.

Background:
Dynamic range is computed in terms of number of gray-levels present that have signal content, measuring within the fingerprint area and substantially excluding non-uniform background areas.

Requirement #2 - Fingerprint Artifacts and Anomalies:
Artifacts or anomalies detected on the fingerprint images, which are due to the device or image processing, shall not significantly adversely impact supporting the intended applications.

Background:
The fingerprint images will be examined to determine the presence of artifacts or anomalies which are due to the device or image processing; assessment may include measurements to quantify their degree of severity and significance. Image artifacts or anomalies such as the following non-inclusive list may be investigated:

• jitter noise effects
• localized offsets of fingerprint segments
• sensor segmentation / butt joints
• noise streaks, erratic pixel response
• gray-level saturation
• poor reproduceability

Requirement #3 - Fingerprint Sharpness & Detail Rendition:
The sharpness and detail rendition of the fingerprint images, due to the device or image processing, shall be high enough to support the intended applications.

Background:
Fingerprint sharpness and detail rendition, which is due to the device or image processing, may be investigated by employing suitable, objective image quality metrics, as well as by visual observation of the softcopy-displayed images.

REFERENCES

[Edge] *Photography--Electronic Still-Picture Cameras--Resolution Measurements*, ISO 12233:2000(E), 1 September 2000.

[PIV] *Personal Identity Verification*; information available at: http://csrc.nist.gov/piv-program/

[TestPro] - *Test Procedures for Verifying IAFIS Image Quality Requirements for Fingerprint Scanners and Printers*, MITRE Corporation Technical Report, MTR-050000016, April 2005. Document available at: http://www.mitre.org/tech/mtf
This document covers Appendix F testing; it can be used as an interim document for test guidance for PIV spec testing.

[Verify] - *Information Technology - Biometric Performance Testing and Reporting - Part 5: Performance of Biometric Access Control Systems,* ISO/IEC JTC 1/SC 37 N1247, ISO/IEC 1st WD 19795-5, ISO/IEC JTC1/SC37/WG5, 22 August 2005