Specifications for Fast Tenprint Capture Devices

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1. Scope and Purpose

The objective of fast tenprint capture (FTC) devices is to obtain 2-d rolled-equivalent fingerprint images from the 3-d finger objects for ten fingers at the faster speed than live scanners do. It is mandatory that the 2-d rolled-equivalent fingerprint images be matchable with those captured using certified live scanners, which exist numerously in the current fingerprint systems. The specifications are applied to evaluate such FTC devices.

Since the fingerprint images captured from 3-d finger objects must be converted to 2-d rolled-equivalent fingerprint images, this technology involves not only optical system (hardware) but also conversion algorithms (software). Hence, the specifications stipulated in this document are used to evaluate the resultant effect of these two factors rather than just the effect of the optical system as live scanners do.

The evaluation of FTC devices is threefold. The first is the absolute measurement, i.e., stipulating the specifications and designing targets to implement specifications. The second is the relative measurement for interoperability, namely, matching 2-d rolled-equivalent fingerprint images produced using FTC devices against those collected from certified live scanners. The third is the evaluation of the real time of completing one transaction carried out by an FTC device.

The specifications set in the absolute measurement shall be supported by the results from the relative measurement. The interactions between the absolute measurement and the relative measurement shall take several iterations. Once it is done, only the absolute measurement shall be invoked to evaluate FTC devices.

2. The Absolute Measurement

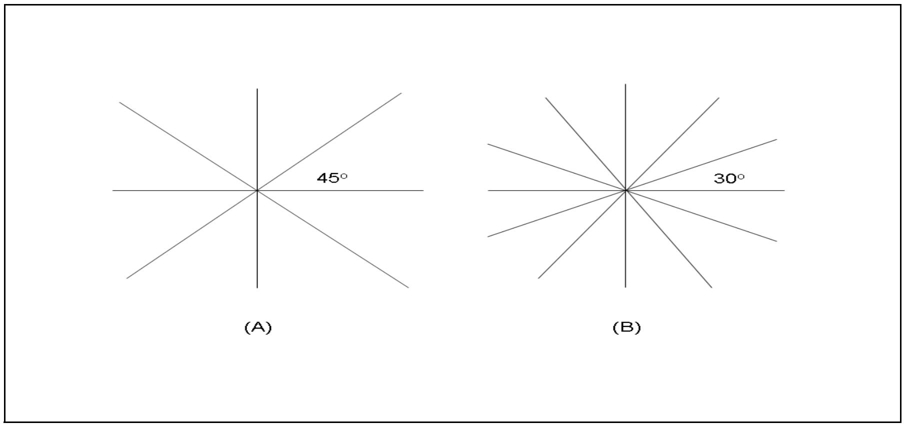
2.1 3-D Targets

The shape and size of the 3-d targets for 10 fingers are determined by statistically analyzing the existing databases. The unknown geometric parameters of 3-d targets are the shape of the cross section, the curvature of the surface, and the length, etc. 3-d targets may start with regular shaped targets such as cylinder, truncated cone, etc, and then be evolved to complicated shaped targets with an artificial ridge-valley structure.

The reflectance intensities on the 3-d targets shall be designed in such a way that for instance the sine waves and the square waves on the flattened plane of the target surface with least distortion are equivalent to those on the flat surface. Or, 3-d targets with developable surface are employed but located in different inclinations inside the capture space of FTC devices.

These targets will be used in all the absolute-measurement evaluations as presented below.

2.2 Test Directions



There are two possibilities. The test directions are four ways as shown in Figure (A) or six ways as shown in Figure (B).

2.3 Measurement Accuracy

It is a nondeterministic process to obtain 2-d rolled-equivalent fingerprint images from the 3-d finger objects for ten fingers using FTC devices. Hence, to determine the values of parameters in the following absolute measurement, a sufficient number of measures could be carried out. Then, the measurement accuracy, such as 95% confidence intervals, etc., can be estimated.

2.4 Geometric Accuracy

Assume that X is the arc length of two points in a 3-d target and Y is the distance of two corresponding points in the corresponding 2-d rolled-equivalent image. X and Y are in inches[1]. The arc length is defined as the length along a curve. It can be computed in the 3-d Cartesian coordinates using the formula,

$$s \equiv \int_{\gamma} |\, dl \,| = \int_{\gamma} \sqrt{dx^2 + dy^2 + dz^2}$$

where *dl* is a differential displacement vector along a curve γ.

The specifications of the geometric accuracy are listed in the following table.

Resolution	X	D = |Y – X|
500 ppi	$0.00 < X \leq 0.07$	$D \leq 0.0007$ (?)
	$0.07 \leq X \leq 1.50$	$D \leq X$ * 1% (?)
1000 ppi	$0.00 < X \leq 0.07$	$D \leq 0.0005$ (?)
	$0.07 \leq X \leq 1.50$	$D \leq X$ * 0.71% (?)

[1] 1 inch is equal to 25.4 mm.

For 500 ppi, 0.07 inches contain 35 pixels, 1.50 inches contain 750 pixels, and 0.0007 inches are about 1/3 pixel. For 1000 ppi, 0.07 inches contain 70 pixels, 1.50 inches contain 1500 pixels, and 0.0005 inches are about ½ pixel.

2.5 Spatial Frequency Response

In analogy to the definition of Michelson contrast, the modulation of a target is defined as

$$M_t = \frac{R_{max} - R_{min}}{R_{max} + R_{min}},$$

where R_{max} and R_{min} are the maximal and minimal reflectance intensities on the target, respectively. The modulation of an image is defined as

$$M_i = \frac{G_{max} - G_{min}}{G_{max} + G_{min}},$$

where G_{max} (G_{min}) is the maximum (minimum) grayscale value taken from all average maximum (minimum) grayscales, e.g., corresponding to all peaks (valleys) of a sine-wave image, where the average is taken along the direction perpendicular to the sine wave direction.

Then, the modulation transfer function (MTF) of the device with respect to the spatial frequency ν of the wave on the target is defined as

$$\text{MTF}(\nu) = M_i / M_t .$$

Generally speaking, as the spatial frequency ν increases, the modulation transfer function MTF (ν) decreases. Thus, MTF (ν) describes the characteristics of the spatial frequency response of FTC devices, which is the resultant effect of the optical system and the conversion algorithms. It also demonstrates how the contrast is transmitted from the real object (target) to the 2-d rolled-equivalent image.

In particular, if the target is formed using square wave (i.e., bar target), MTF turns out to be contrast transfer function (CTF). CTF can be calculated in terms of frequency ν by

for 500 ppi devices while ν varies from 1.0 to 10.0 cycles/mm,

$$\text{CTF}(\nu) = 3.04105 * 10^{-4} * \nu^2 - 7.99095 * 10^{-2} * \nu + 1.02774 ,$$

for 1000 ppi devices while ν varies from 1.0 to 20.0 cycles/mm,

$$\text{CTF}(\nu) = -1.85487 * 10^{-5} * \nu^3 + 1.41666 * 10^{-3} * \nu^2 - 5.73701 * 10^{-2} * \nu + 1.01341 .$$

The unknown reflectance intensities on a target corresponding to the maximal and minimal grayscale values, i.e., G_{max} and G_{min}, on an image can be obtained by using a calibration curve. The calibration straight line is derived using the least squares simple linear regression between the reflectance intensities of 14 gray patches and 14 average grayscales of the corresponding images produced by the device. A sample of calibration straight line is shown in the following figure.

While sampling spatial frequency response, the output images of 3-d sine wave target or 3-d square wave target shall not exhibit any significant amount of aliasing.

If sine wave target is used, the requirement of minimum MTF (ν) is listed in the following table. If square wave target is used, the requirement of minimum CTF (ν) can be obtained using the above two formulas.

Frequency (cy/mm)	Minimum MTF (ν) for 500 ppi	Minimum MTF (ν) for 1000 ppi
1	0.905 (?)	0.925 (?)
2	0.797 (?)	0.856 (?)
3	0.694 (?)	0.791 (?)
4	0.598 (?)	0.732 (?)
5	0.513 (?)	0.677 (?)
6	0.437 (?)	0.626 (?)
7	0.371 (?)	0.579 (?)
8	0.312 (?)	0.536 (?)
9	0.255 (?)	0.495 (?)
10	0.200 (?)	0.458 (?)
12		0.392 (?)
14		0.336 (?)
16		0.287 (?)
18		0.246 (?)
20		0.210 (?)

2.6 Signal-to-Noise Ratio

In image processing, the signal-to-noise ratio (SNR) is usually defined as the ratio of the mean of grayscales of all pixels in an area on an image to the standard deviation of those grayscales. The target used to create the image is a 3-d surface as indicated in Section 2.1. The target shall be located in anywhere inside the capture space of FTC devices. The test field within an image is a random 0.25 inch by 0.25 inch (i.e., 6.35 mm by 6.35 mm) area. While testing SNR, at least 1000 random samples of grayscales are selected from the test field.

If a 3-d white reference target with high reflectance and a 3-d black reference target with low reflectance are used and located alternately in the same position inside the capture space of FTC devices, the white SNR and the black SNR are defined, respectively, as

$$SNR_{white} = \frac{\overline{G}_{white} - \overline{G}_{black}}{\sigma_{white}}$$

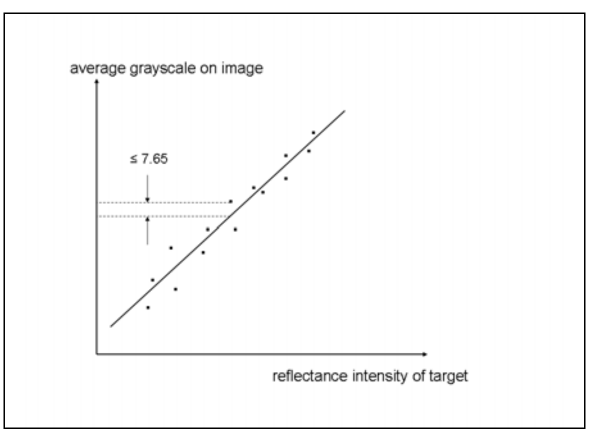
and

$$SNR_{black} = \frac{\overline{G}_{white} - \overline{G}_{black}}{\sigma_{black}}$$

where $\overline{G}$ is the mean of grayscales of all pixels inside the test field on an image and σ is the unbiased standard deviation derived from the same set of grayscales. In order to obtain a true measure of the standard deviation, $\overline{G}_{white}$ ($\overline{G}_{black}$) shall be several grayscales below (above) the system's highest (lowest) obtainable grayscale. Both white SNR and black SNR shall be greater than or equal to 125. At least 97.0% of test shall satisfy this requirement.

2.7 Grayscale Linearity

All residuals of average grayscales from the simple regression straight line shall be less than or equal to 7.65 grayscales. The estimated regression straight line is derived using the least square fit criterion between 14 reflectance intensities of 3-d gray-patch targets and 14 average grayscales of the corresponding images produced by FTC devices. This is schematically depicted in the following figure.



2.8 Grayscale Uniformity

A 3-d white reference target and a 3-d black reference target shall be used to determine the grayscale uniformity. The FTC device shall be set up in such a way that the 3-d white reference target is below device saturation level and the 3-d black reference target is above device dark current level.

2.8.1 Uniformity of Adjacent Lines along Test Directions

The uniformity of adjacent lines along test directions is measured by the difference between two means of grayscales corresponding to any two adjacent lines with length of greater than or equal to 9 pixels on an image, while target shall be randomly located inside the capture space of FTC devices. The difference shall not be more than 2.0 grayscales using 3-d white reference target and 1.0 grayscales using 3-d black reference target.

2.8.2 Small Area Uniformity

The small-area uniformity is measured by the maximum difference between the grayscale of any individual pixel within a random 0.25-inch-by-0.25-inch (i.e., 6.35-mm-by-6.35-mm) test field on an image and the mean of grayscales of all pixels in the same test field, while target shall be randomly located inside the capture space of FTC devices. The maximum difference shall not be more than 22.0 grayscales using 3-d white reference target and 8.0 grayscales using 3-d black reference target.

2.8.3 Small Area to Small Area Uniformity

The small-area-to-small-area uniformity is measured by the difference between two average grayscales of all pixels corresponding to any two non-contiguous 0.25-inch-by-0.25-inch (i.e., 6.35-mm-by-6.35-mm) test fields on an image, while targets shall be randomly located inside the capture space of FTC devices. The difference shall not be more than 12.0 grayscales using 3-d white reference target and 3.0 grayscales using 3-d black reference target.

2.9 Grayscale Dynamic Range

The grayscale dynamic range is defined as the total number of grayscales used to present the signal on an image. The grayscale ranges from 0 (black) to 255 (white) for 8-bit storage on a pixel. Not only shall the grayscale be considered, but the frequency of the grayscale occurring on an image shall also be taken into account while dealing with the distribution of grayscales employed on an image captured by FTC devices. Thus, some threshold shall be imposed in order to determine the grayscale dynamic range on an image. In other words, only those grayscales whose probabilities of appearance are above a threshold shall be counted. In the meantime, background, card format lines, boxes, and text shall be excluded.

The test of grayscale dynamic range shall be taken place with sets of images captured by FTC devices in a stratified way (i.e., dark, medium, and light images) and/or sets of FTC devices produced by the vendor. At least 80.0% of the captured individual fingerprint images shall have a grayscale dynamic range of at least 200 grayscales, and at least 99.0% shall have a grayscale dynamic range of at least 128 grayscales.

3. The Relative Measurement

The procedure of the evaluation of the relative measurement shall be progressive, since it may involve sample collection. Once the test passes the low level, then the test progresses to the next level. The quantitative analyses will be shown, as the relative measurement develops.

3.1 A Primitive Test

The 2-d rolled-equivalent fingerprint image created by FTC devices shall be reverse-free and mirror image. The distribution of grayscales of all pixels excluding the background on an image shall be bimodal distribution rather than unimodal distribution.

3.2 A Genuine-Match Test

The same subject's 2-d rolled-equivalent images of fingers (right-index finger, left-index finger, and then other eight fingers) created using FTC devices shall be matchable with those captured using certified live scanners, in terms of the number and location of minutiae, etc.

3.3 Reality Tests

The Gallery is formed by fingerprint images of a set of different subjects captured using a certified live scanner. The Probe I is formed by different fingerprint images of the same set of subjects captured using the same certified live scanner. The Probe II is formed by 2-d rolled-equivalent fingerprint images of the same set of subjects created using FTC device. ROC curves shall be generated by employing the-state-of-the-art fingerprint-image extracting and matching technology. Then, the ROC curve generated from the Probe II and the Gallery shall be compared to the ROC curve generated from the Probe I and the same Gallery. The difference shall be within the tolerance.

The Gallery can also be formed by different 2-d rolled-equivalent fingerprint images of the same set of subjects produced using FTC device. In such cases, a subject does FTC device twice as well as certified live scanner twice, respectively. The fingerprint images created using FTC device can be mixed with those captured using certified live scanners to form gallery and probe. Thus, more reality ROC-curve tests can be taken place.

If the sample size is large enough, the operational criterion, i.e., TAR at a fixed FAR shall be invoked; otherwise, it has no statistical significance. If the sample size is not large enough, the area under an ROC curve shall be employed.

4. The Speed

The speed of FTC device is defined to be the real time of completing one transaction. And the real time of completing one transaction is equal to the sum of the time of positioning ten fingers into the right position inside the capture space of FTC device plus the processing time executed by the system (hardware & software) including the time from capturing fingers to converting to 2-d rolled-equivalent images. The evaluation of the speed of FTC device is one way to test the usability of devices. FTC devices shall be user friendly. The speed of FTC device shall not be higher than 15 seconds per transaction. This evaluation can be done by sample collection.

References

1. APPENDIX F: IAFIS Image Quality Specifications, IAFIS-DOC-01078-7.1, May 2, 2005; available at http://www.mitre.org/tech/mtf/spec_test.zip.
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4. Norman B. Nill, Test Procedures for Verifying Image Quality Requirements for Personal Identity Verification (PIV) Single Finger Capture Devices, MITRE technical report, MTR 060170, December 2006; available at http://www.mitre.org/tech/mtf/spec_test.zip.
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