Development of NFIQ 2.0

Quality Feature Definitions

Version 0.5

NIST National Institute of Standards and Technology U.S. Department of Commerce

Bundesamt für Sicherheit in der Informationstechnik

secunet

h_da HOCHSCHULE DARMSTADT UNIVERSITY OF APPLIED SCIENCES

Fraunhofer IGD

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Notation

An overview of the common notation used throughout this document is given in Table 1-1 and an illustration of the image indexing is given in Figure 1-1.

Variable	Description
$\boldsymbol{X}$	Image width in pixels (horizontal).
$\boldsymbol{Y}$	Image height in pixels (vertical).
$\boldsymbol{I}(\boldsymbol{x},\boldsymbol{y})$	Image intensity where $I(1,1)$ denotes the pixel in the upper left corner.
$\boldsymbol{B_w}$	Block width.
$\boldsymbol{B_h}$	Block height.
$\boldsymbol{V}(\boldsymbol{i},\boldsymbol{j})$	Image block where $V(1,1)$ denotes the block in the upper left corner.

Table 1-1. Common notation used in this document.

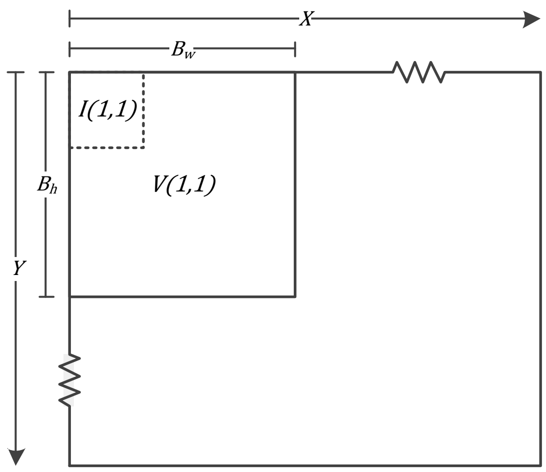


Figure 1-1. Illustration of block and pixel indexing within an image I. Shown is the pixel $I(1,1)$, the block $V(1,1)$, the block dimensions B_w, B_h and the image dimensions X and Y.

1 Introduction

This document provides definitions of potential quality features implemented for the NIST Fingerprint Image Quality 2.0 (NFIQ 2.0) algorithm. The structure of the document is such that each quality feature definition contains a summarizing table, a high level feature description, and a step-by-step algorithm listing, which optionally has in depth descriptions of particular steps. Additionally, algorithm processing steps are illustrated using two images (one of high quality, one of low quality).

2 Frequency Domain Analysis

Quality Feature Summary	
Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) – Clause 6.2.2.3
NFIQ 2.0 Identifier	FDA_#
Acronyms	FDA

Table 2-1. Frequency Domain Analysis summary.

2.1 Description

The Frequency Domain Analysis algorithm operates in a block-wise manner. A signature of the ridge-valley structure is extracted and the DFT is computed to determine the frequency of the sinusoid following the ridge-valley structure.

2.2 Variables

Name	Default	Description
I	-	Input image
B_h	32	Block height in pixels
B_w	32	Block width in pixels
I_{mask}	-	Segmentation mask

Table 2-2. Frequency Domain Analysis input variables.

2.3 Algorithm

2.a For each block $V(i,j)$ determine the dominant ridge flow orientation.

2.b Rotate the block such that the dominant ridge flow is perpendicular to the x-axis.

2.c Crop regions of block such that no invalid regions are included in the block.

2.d Calculate, in the rotated block, the mean value along the y-axis (ridge flow) to derive the ridge-valley signature $T(x)$.

2.e Calculate the DFT Fourier spectrum of T as $F(T)$

2.f Discard the DC component of $F(T)$ resulting in $F(T)'$ containing the remaining coefficients.

2.g Determine the term index F_{max} in $F(T)'$ as the term with the largest magnitude $A(F_{max})$.

2.h The final Frequency Domain Analysis score is the mean of scores assigned to foreground blocks as defined by I_{mask}.

2.4 Extracting the ridge-valley signature

$$T(x) = \frac{1}{2r+1} \sum_{k=-r}^{r} I(x,k)$$

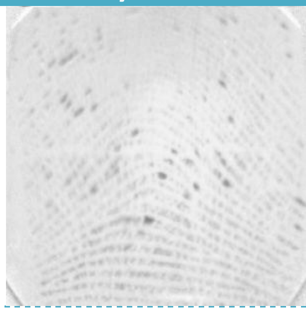
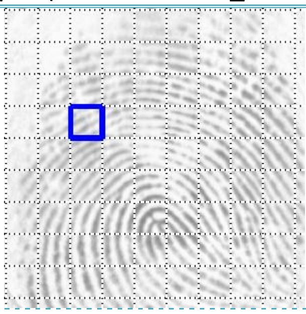
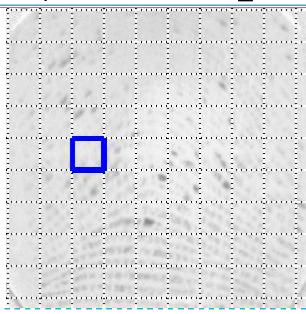
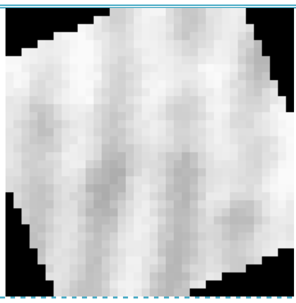
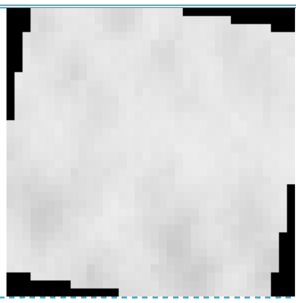
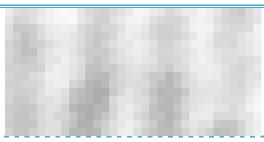
2.5 Computing the Frequency Domain Analysis score

$$Q_{FDA} = \frac{A(F_{max}) + 0.3(A(F_{max}-1) + A(F_{max}+1))}{\sum_{F=1}^{N/2} A(F)}$$

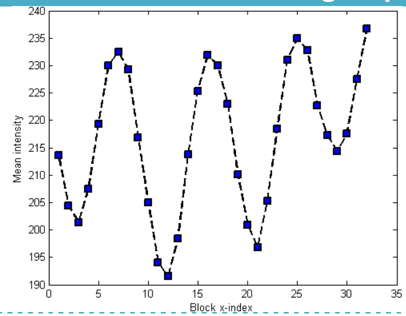
2.6 Notes

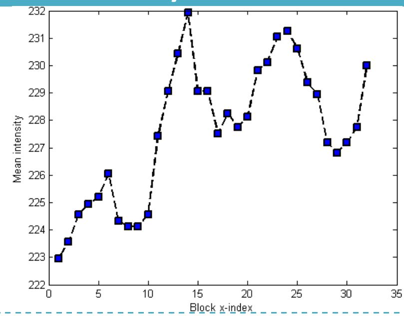
The value of Q_{FDA} is undefined if $F_{max} = 1$ or $F_{max} = A(end)$ as $A(0)$ is not a valid index. Workaround in that case is to set $Q_{FDA} = 1$. Despite ISO recommendation of a high quality value indicating a high quality, this is not the case for Frequency Domain Analysis as specified in ISO/IEC TR 29794-4:2010.

2.7 Processing steps

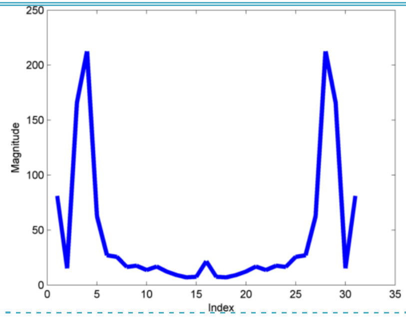
Processing steps for Frequency Domain Analysis	
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Input with block grid and current block marked in blue	
	
Zoomed view of current block	
	
Block rotated	
	
Block cropped	

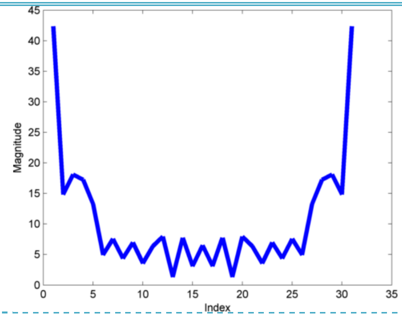
Processing steps for Frequency Domain Analysis



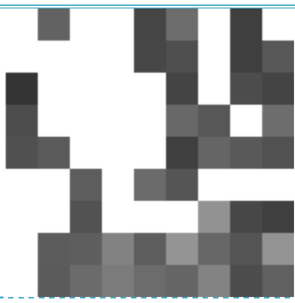


Block mean intensity values





Block DFT



Map of FDA quality values where with grey value correspond to high Q_{FDA} value (low local quality).

Table 2-3. Visualization of processing steps for Frequency Domain Analysis.

3 Gabor Segment

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	GS_#
Acronyms	GSG, GaborSeg

Table 3-1. Gabor Segment summary.

3.1 Feature Description

Same as Gabor with the exception that the image is initially convolved with a 2D Gaussian kernel with $\sigma = 8$ instead of $\sigma = 1$. Additionally a quantization to 2 levels is applied before computing the final quality score.

3.2 Variables

Name	Default	Description
I	-	Input image.
σ_x	6	2D Gaussian standard deviation in x-direction.
σ_y	6	2D Gaussian standard deviation in y-direction.
n	4	Size of filter bank (orientations of the Gabor wave).
f	0.1	Gabor filter frequency .

Table 3-2. Gabor Segment input variables.

3.3 Algorithm

3.a Convolve input image with a 2D Gaussian kernel with $\sigma = 8$ and subtract from input image
3.b Compute the Gabor response of the image for each orientation
3.c Convolve the magnitude (complex modulus) of each Gabor response with a 2D Gaussian kernel with $\sigma = 6$
3.d Compute the standard deviation of the Gabor magnitude response values at each location yielding a map of standard deviations.
3.e Quantize the standard deviation map into two levels.
3.f Sum the map standard deviations and normalize according to number of sample points (typically image size) to produce the final Gabor quality score.

3.4 Quantize to two levels

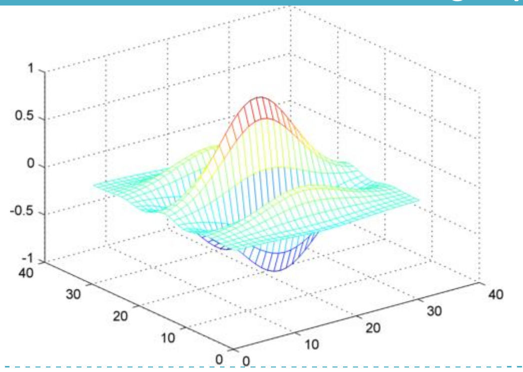
Quantizing the map of standard deviations into two levels is done by first determining the cumulative distribution function for pixel intensity values. Next a threshold is determined such that the probability of a pixel belonging to background is the same as that for belonging to the foreground. Thus the quantized image can serve as a foreground segmentation.

3.5 Notes

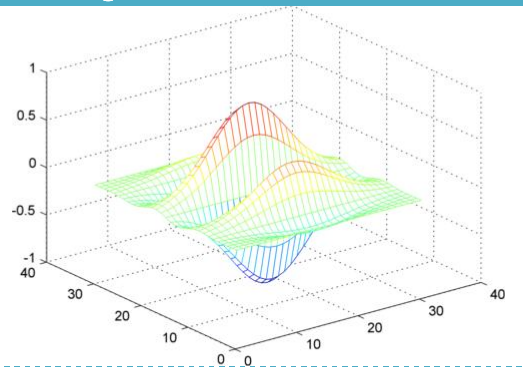
The Gabor Segment quality feature is resolution dependent. The given defaults assume 500ppi.

3.6 Processing steps

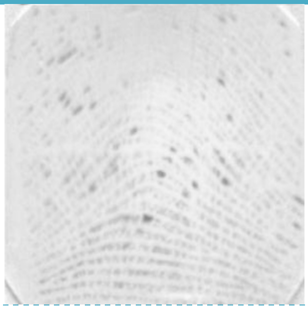
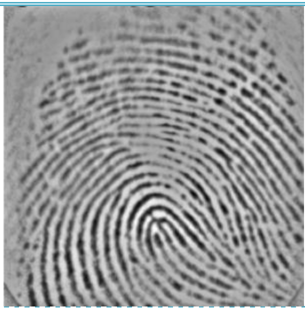
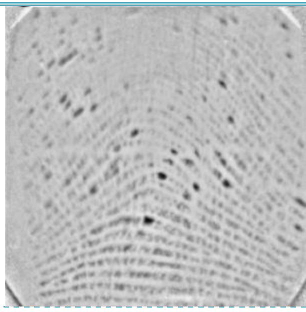
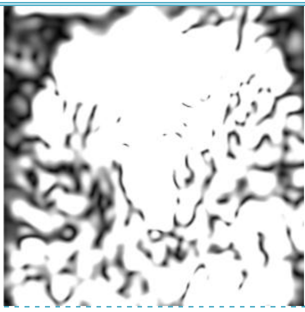
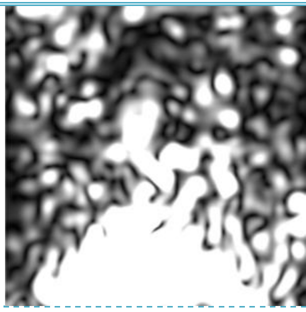
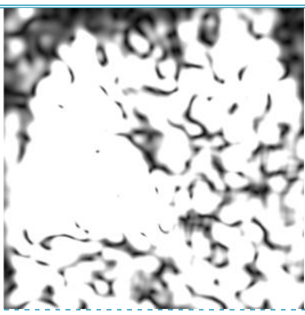
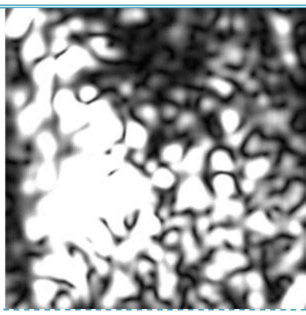
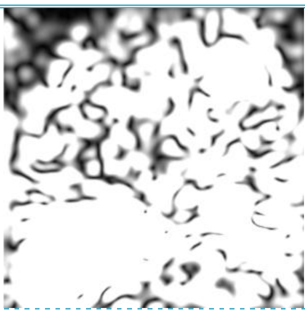
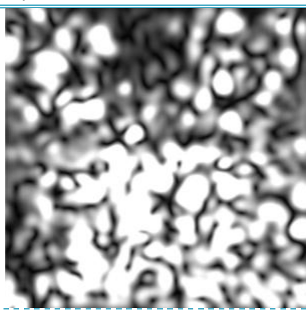
Processing steps for Gabor Segment



Real part of Gabor filter



Imaginary part of Gabor filter

Processing steps for Gabor Segment	
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Input image subtracted with input image convolved with Gaussian	
	
Gabor response at orientation 0	
	
Gabor response at orientation 1/4	
	
Gabor response at orientation 2/4	

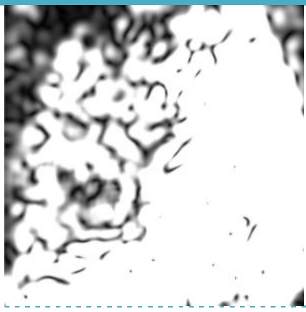
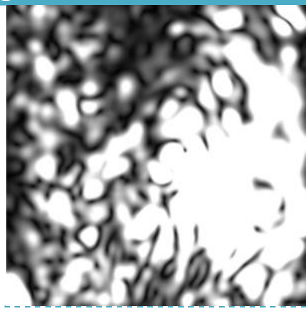
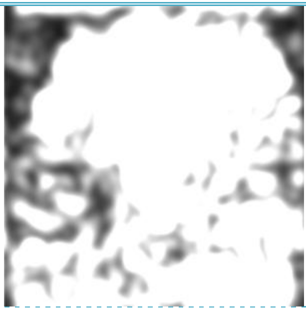
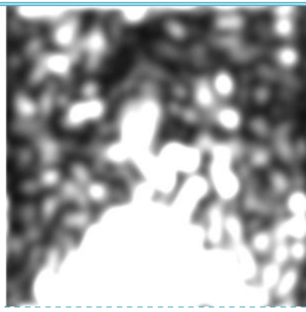
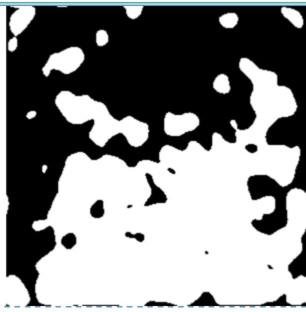
Processing steps for Gabor Segment	
	
Gabor response at orientation 3/4	
	
Standard deviation of filter responses	
	
Segmentation of standard deviation of filter responses into two levels	

Table 3-3. Visualization of processing steps in Gabor Segment.

4 Gabor Shen

Quality Feature Summary	
Origin	L. Shen, A. C. Kot, and W. M. Koo. Quality measures of fingerprint images.
NFIQ 2.0 Identifier	GSh_#
Acronyms	GSH

Table 4-1. Gabor Shen summary.

4.1 Feature Description

Gabor based feature separating blocks into two classes: good and bad. Quality is the ratio between number of foreground blocks and number of foreground blocks marked as poor.

4.2 Variables

Name	Default	Description
I	-	Input image.
T_b	1	Threshold for foreground/background segmentation.
T_q	2	Threshold for poor/good block segmentation.

Table 4-2. Gabor Shen input variables.

4.3 Algorithm

4.a Divide the image into blocks of size $b \times b$.
4.b Compute the n Gabor filters.
4.c For each block centered at pixel (x, y) compute the n Gabor responses.
4.d For each block, compute the standard deviation G of the n Gabor responses in that block.
4.e Use G to segment foreground/background of the image
4.f Determine the set of blocks, V_F, belonging to the foreground as those where $\mu_i > T_b$
4.g Determine the set of blocks, V_P, which are of poor quality and foreground as those where $(\mu_i > T_b) \wedge (\mu_i < T_q)$
4.h Compute the quality score $Q_{GABORSHEN}$ as $1 - \frac{V_P}{V_F}$

4.4 Notes

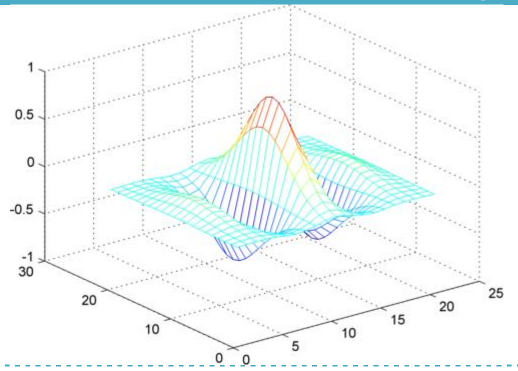
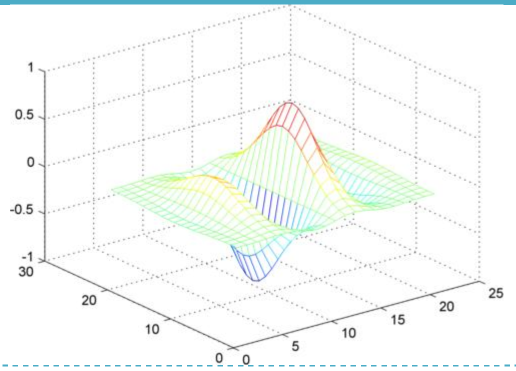
The Gabor Shen quality feature is resolution dependant. The given defaults assume 500ppi.

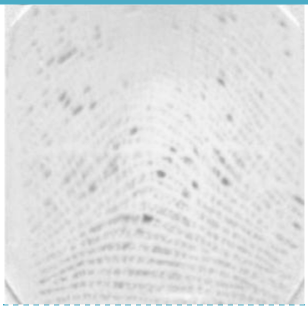
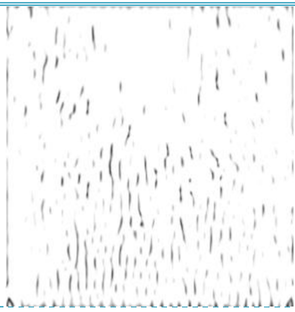
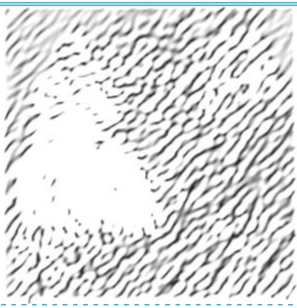
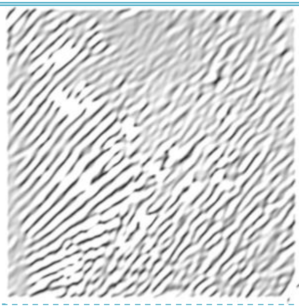
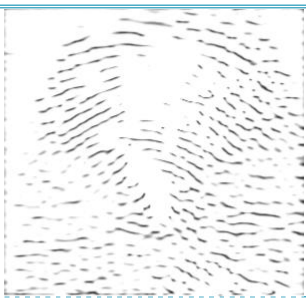
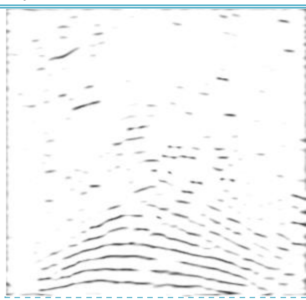
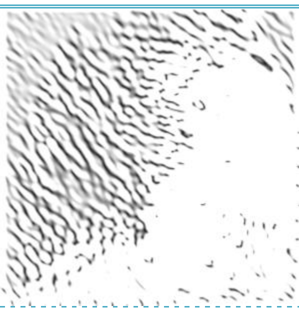
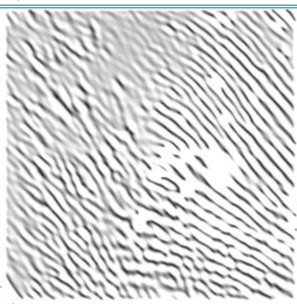
Shen et. al suggest the following :

$$\sigma_x = \sigma_y = 4$$
$$f = 0.12$$
$$n = 8$$
$$b = 30$$

T_b and T_q are manually determined according to dataset.

4.5 Processing steps

Processing steps for Gabor Shen	
	
Real part of Gabor filter	Imaginary part of Gabor filter

<table>
<tr><th colspan="2">Processing steps for Gabor Shen</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Input (FVC2000Db1 1_1.bmp)</td><td>Input (FVC200Db1 100_1.bmp)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Gabor response at orientation 0</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Gabor response at orientation 1/4</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Gabor response at orientation 2/4</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Gabor response at orientation 3/4</td></tr>
</table>

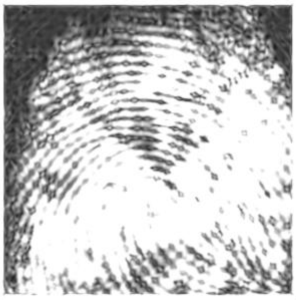
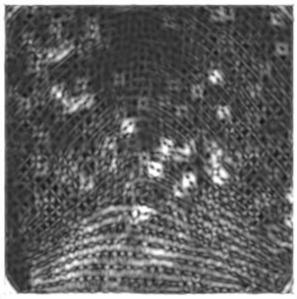
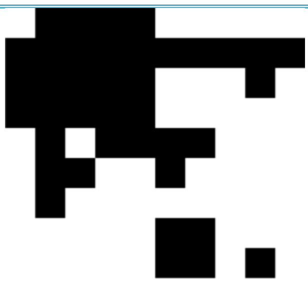
Processing steps for Gabor Shen	
	
Standard deviation of filter responses	
	
Blockwise mean of filter responses	
	
Foreground blocks	
	
Blocks marked as poor	

Table 4-3. Visualization of processing steps in Gabor Shen.

5 Gabor

Quality Feature Summary	
Origin	Olsen, Xu, Busch, Gabor Filters as Candidate Quality Measure for NFIQ
NFIQ 2.0 Identifier	GABOR_#
Acronyms	GAB

Table 5-1. Gabor summary.

5.1 Feature Description

The Gabor quality feature operates on a per-pixel basis by calculating the standard deviation of the Gabor filter bank responses. The size of the filter bank is used to determine a number of filters oriented evenly across the half circle. The strength of the response at a given location corresponds to the agreement between filter orientation and frequency in the location neighborhood. For areas in the fingerprint image with a regular ridge-valley pattern there will be a high response from one or a few filter orientations. In areas containing background or unclear ridge-valley structure the Gabor response of all orientations will be low and constant.

5.2 Variables

Name	Default	Description
I	-	Input image
σ_x	6	2D Gaussian standard deviation in x-direction
σ_y	6	2D Gaussian standard deviation in y-direction
n	4	Size of filter bank (orientations of the Gabor wave)
f	0.1	Gabor filter frequency

Table 5-2. Gabor input variables.

5.3 Algorithm

5.a Convolve input image with a 2D Gaussian kernel with $\sigma = 1$ and subtract it from the input image to give $\bar{I}$

5.b Compute the Gabor response of $\bar{I}$ for each orientation θ

5.c Convolve the magnitude (complex modulus) of each Gabor response with a 2D Gaussian kernel with $\sigma = 4$

5.d Compute the standard deviation of the Gabor magnitude response values at each location yielding a map of standard deviations.

5.e Sum the map of standard deviations and normalize according to number of sample points (typically image size) to produce the final Gabor quality score.

5.4 The Gabor filter

The general form of the complex 2D Gabor(Daugman, 1985) filter h_{Cx} in the spatial domain is given by:

$$h_{Cx}(x, y; f, \theta, \sigma_x, \sigma_y) = \exp\left(-\frac{1}{2}\left(\frac{x_\theta^2}{\sigma_x^2} + \frac{y_\theta^2}{\sigma_y^2}\right)\exp(j2\pi f x_\theta)\right)$$

where

$$x_\theta = x\sin\theta + y\cos\theta$$

and

$$y_\theta = x\cos\theta - y\sin\theta$$

and f is the frequency (cycles/pixel) of the sinusoidal plane wave along the orientation θ. The size of the Gaussian smoothing window is determined byσ_x, σ_y

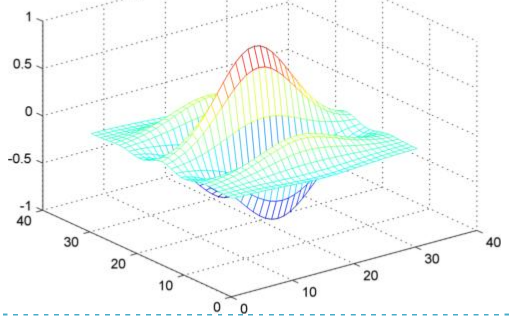
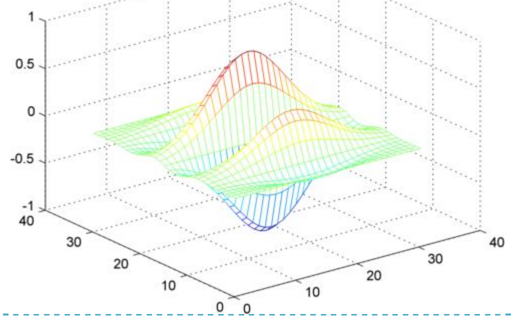
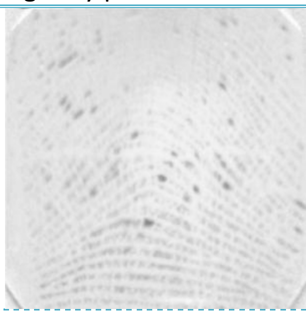
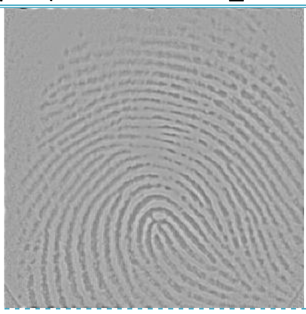
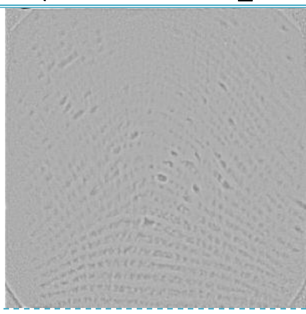
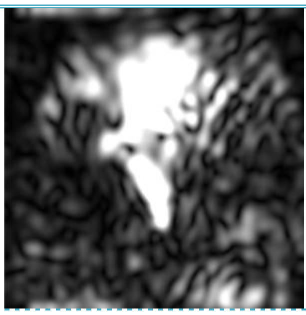
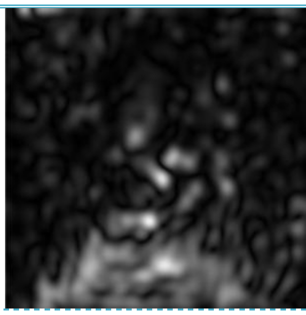
The filter bank size n is used to compute the differently oriented Gabor filters composing the filter bank. Computing θ given n is done as :

$$\theta = \frac{k-1}{n\pi}, k = 1, \dots, n$$

5.5 Notes

The Gabor quality feature is resolution dependent. The given defaults assume 500ppi.

5.6 Processing steps

Processing steps for Gabor	
	
Real part of Gabor filter	Imaginary part of Gabor filter
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Subtraction of image convolved with Gaussian.	
	
Gabor response for filtered image at orientation 0	

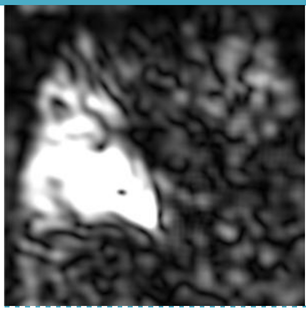
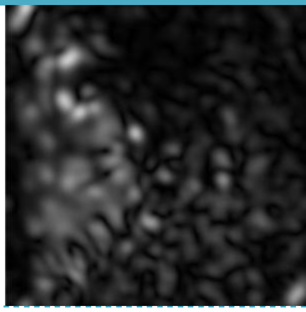
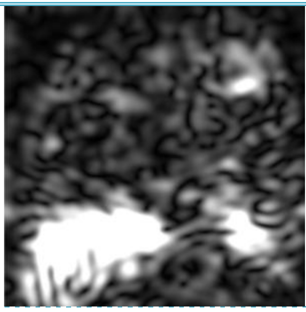
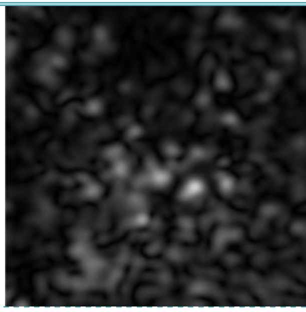
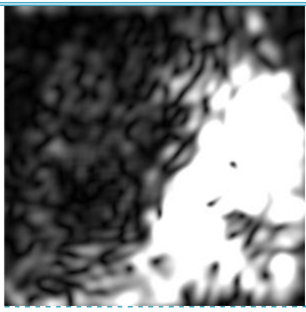
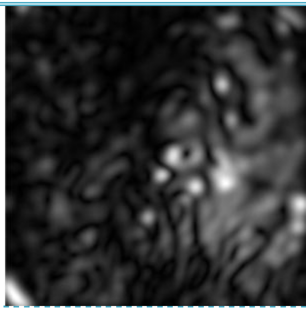
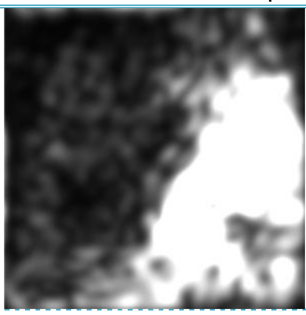
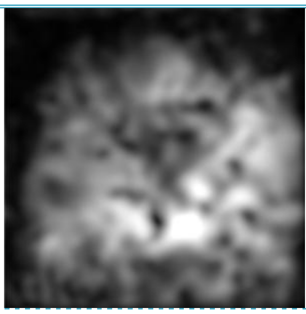
Processing steps for Gabor	
	
Gabor response for filtered image at orientation 1/4	
	
Gabor response for filtered image at orientation 2/4	
	
Gabor response for filtered image at orientation 3/4	
	
Gaussian filtered Gabor response for filtered image at orientation 3/4	
	
Standard deviation of Gaussian filtered responses	

Table 5-3. Visualization of processing steps in Gabor.

6 Local Clarity Score

Quality Feature Summary	
Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) – Clause 6.2.2.2
NFIQ 2.0 Identifier	
Acronyms	LCS, Ridge-valley Structure

Table 6-1. Local Clarity Score summary.

6.1 Feature Description

Local Clarity Score (LCS) computes the block wise clarity of ridge and valleys by applying linear regression to determine a gray-level threshold, classifying pixels as ridge or valley. A ratio of misclassified pixels is determined by comparing with the normalized ridge and valley width of that block.

6.2 Variables

Name	Default	Description
I	-	Input image
B_h	32	Block height in pixels
B_w	32	Block width in pixels
I_{mask}	-	Segmentation mask

Table 6-2. Local Clarity Score input variables.

6.3 Algorithm

6.a For each block V_0 in the image determine the dominant ridge flow orientation to create an orientation line which is perpendicular to the ridge flow.
6.b Align V_0 such that the orientation line is horizontal to create V_1.
6.c From V_1 extract a block V_2 which is centered around the orientation line.
6.d Compute the average profile V_3 of V_2.
6.e Determine a threshold DT by applying linear regression on V_3.
6.f Determine the proportion of misclassified pixels β and α in the ridge and valley regions.
6.g Determine the normalized ridge width and valley width W_r and W_v.
6.h Compute the final quality score Q_{LCS}.

6.4 Computing the average profile of a block

Given the block V_2 the average profile is obtained by

$$V_3(x) = \frac{\sum_{y=1}^{M} V_2(x,y)}{M}$$

where M is the height of the block.

6.5 Determining the proportion of misclassified pixels

For a block V_2 there are v_T pixels in the valley region and v_B pixels in the valley region with intensity lower than a threshold DT. Similarly there are r_T pixels in the ridge region and r_B pixels in the ridge region with intensity lower than a threshold DT. α and β are expressions of these ratios.

$$\alpha = \frac{v_B}{v_T}$$
$$\beta = \frac{r_B}{r_T}$$

6.6 Determining the normalized ridge and valley width

The normalized valley width $\overline{W}_v$ and the normalized ridge width $\overline{W}_r$ are determined

$$\overline{W}_v = \frac{W_v}{\left(\frac{S}{125}\right) W^{max}}$$
$$\overline{W}_r = \frac{W_r}{\left(\frac{S}{125}\right) W^{max}}$$

where S is the scanner resolution in dpi, W^{max} is the estimated ridge or valley width for an image with 125 dpi resolution, and W_v and W_r are the observed valley and ridge widths. According to (ISO/IEC, 2010) $W^{max} = 5$ is reasonable for 125 dpi resolution.

6.7 Computing the Local Clarity Score

The final quality score is computed using the average value of α and β in valid ridge and valley regions:

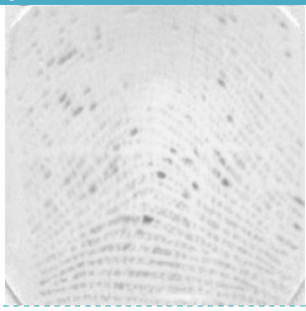
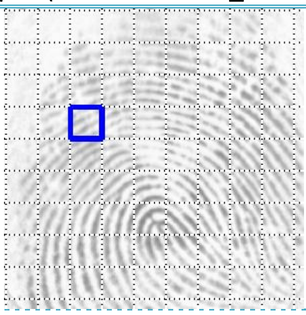
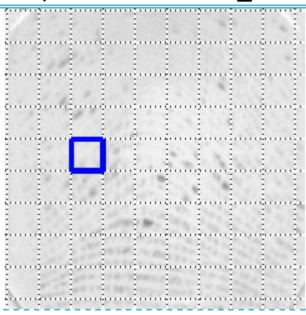
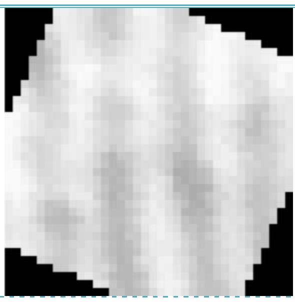
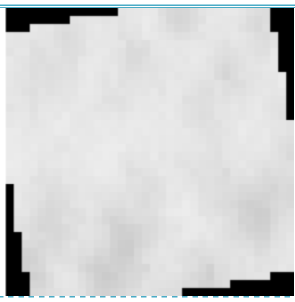
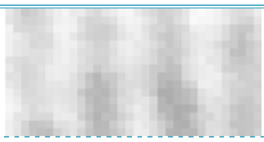
$$Q_{LCS} = \begin{cases} \left(1 - \left(\frac{\alpha + \beta}{2}\right)\right) * 100, & \left(W_v^{nmin} < \overline{W}_v < W_v^{nmax}\right) \wedge \left(W_r^{nmin} < \overline{W}_r < W_r^{nmax}\right) \\ 0, & otherwise \end{cases}$$

where W_r^{nmin} and W_v^{nmin} are the minimum values for the normalized ridge and valley width, and W_v^{nmax} and W_v^{nmax} are the maximum values for the normalized ridge and valley width.

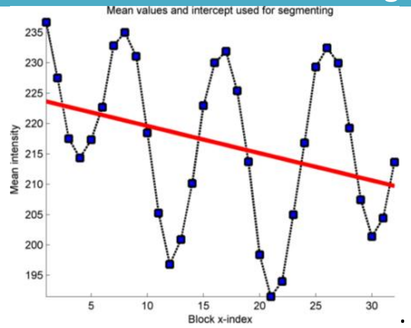
6.8 Notes

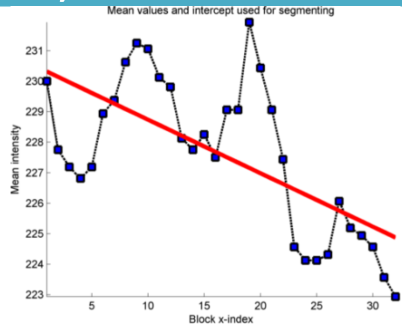
Particular regions inherent in a fingerprint will negatively affect Q_{LCS}. For example, ridge endings and bifurcations or areas with high curvature such as those commonly found in core and delta points.

Processing steps

<table>
<tr><th colspan="2">Processing steps for Local Clarity Score</th></tr>
<tr><td></td><td></td></tr>
<tr><td>Input (FVC2000Db1 1_1.bmp)</td><td>Input (FVC200Db1 100_1.bmp)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Input with grid and block V_0 marked in blue</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Zoomed view of block</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Block rotated to align ridgelines vertically (block V_1)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Extracted section of the block (V_2)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Projected mean gray intensity values (V_3)</td></tr>
</table>

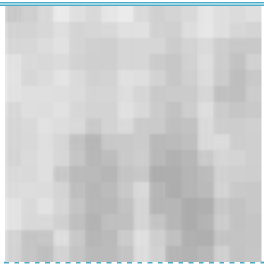
Processing steps for Local Clarity Score



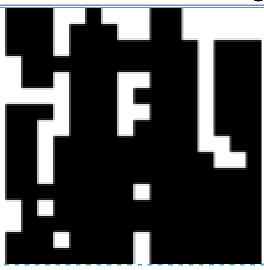


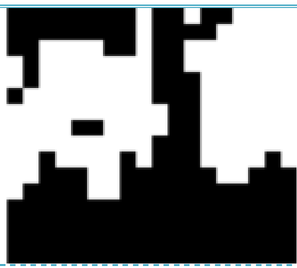
Ridge-valley profile as found by mean values. Red line indicates the threshold for ridge-valley separation

Ridge-valley separation. Ridges shown in black, valleys in white. The mean intensity values are shown above for comparison.



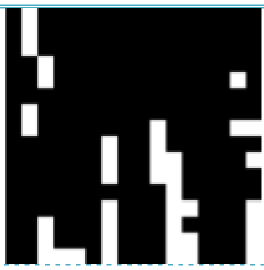
Ridge areas composed into one block.

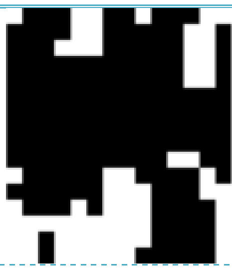




Shown in white are the parts of the fingerprint which were determined to be ridge but do not belong to ridge as defined by the threshold.

Valley areas composed into one block.





Shown in white are the parts of the fingerprint which were determined to be valley but do not belong to valley as defined by the threshold.

Processing steps for Local Clarity Score	
	
Map of local clarity scores. High intensity corresponds to high local clarity.	

Table 6-3. Visualization of processing steps in Local Clarity Score.

7 Mu Mu Block

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	MMB_#
Acronyms	MMB

Table 7-1.Summary of Mu Mu Block.

7.1 Feature Description

Mu Mu Block is the mean of the block wise mean pixel intensity value in the input image.

7.2 Variables

Name	Default	Description
I	-	Input image.
B_h	32	Block height in pixels.
B_w	32	Block width in pixels.

Table 7-2. Mu Mu Block input variables.

7.3 Algorithm

7.a For each block in I compute the mean pixel intensity.
7.b Compute the mean of mean pixel intensities.

8 Mu Mu Sigma Block

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	MMSB_#
Acronyms	MMSB

Table 8-1. Mu Mu Sigma Block summary.

8.1 Feature Description

Mu Mu Sigma Block is the mean of the block wise standard deviation pixel intensity value in the input image subtracted the block wise standard deviation.

8.2 Variables

Name	Default	Description
I	-	Input image.
B_h	32	Block height in pixels.
B_w	32	Block width in pixels.

Table 8-2. Mu Mu Sigma Block input variables.

8.3 Algorithm

8.a For each block in I compute the mean pixel intensity.
8.b Compute the mean of the mean pixel intensities.
8.c Subtract the standard deviation of pixel intensities in I.

9 Mu Sigma Block

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	MSB_#
Acronyms	MSB

Table 9-1. Mu Sigma Block summary.

9.1 Feature Description

Mu Sigma Block is the mean of the block wise standard deviation pixel intensity value in the input image.

9.2 Variables

Name	Default	Description
I	-	Input image.
B_h	32	Block height in pixels.
B_w	32	Block width in pixels.

Table 9-2. Mu Sigma Block input variables.

9.3 Algorithm

9.a Compute the standard deviation of blockwise pixel intensities.
9.b Compute the mean of the standard deviations.

10 Mu

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	Mu_#
Acronyms	MUQ

Table 10-1. Mu summary.

10.1 Feature Description

Mu is the mean pixel intensity value in the input image.

10.2 Variables

Name	Default	Description
I	-	Input image.

Table 10-2. Mu input variables.

10.3 Algorithm

10.a	Compute the mean intensity of I.

10.4 Computing the mean intensity

$$Q_{MU} = \frac{1}{X * Y} \sum_{y=1}^{Y} \sum_{x=1}^{X} I(x, y)$$

11 Orientation Flow

Quality Feature Summary	
Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.3.2.1
NFIQ 2.0 Identifier	OF_#
Acronyms	OF

Table 11-1. Orientation Flow summary.

11.1 Feature Description

Orientation Flow is a measure of ridge flow continuity which is based on the absolute orientation difference between a block and its neighboring blocks.

11.2 Variables

Name	Default	Description
I	-	Input image.
B_h	32	Block height in pixels.
B_w	32	Block width in pixels.
I_{mask}	-	Segmentation mask.
θ_{min}	0	Tolerance to angular change in the orientation flow (in

Table 11-2. Orientation Flow input variables.

11.3 Algorithm

11.a	For each block $V(i, j)$ in I determine the dominant ridge flow orientation.
11.b	Compute the absolute orientation difference $D(i, j)$ for each block $V(i, j)$.
11.c	Compute the local orientation quality score $Q_{loc}(i, j)$ for $D(i, j)$.
11.d	Compute the global orientation flow quality score Q_{OF}.

11.4 Block-wise absolute orientation difference

The ridge flow is determined as a measure of the absolute difference between a block and its neighboring blocks. The absolute difference for block $V(i, j)$ is:

$$D(i, j) = \frac{\sum_{m=-1}^{1} \sum_{n=-1}^{1} |V(i, j) - V(i - m, j - n)|}{8}$$

11.5 Local orientation quality score

The local orientation quality score $Q_{loc}(i,j)$ for the block orientation difference $D(i,j)$ is determined as:

$$Q_{loc}(i,j) = \begin{cases} 100 & , \quad D(i,j) \le \theta_{min} \\ \left(1 - \frac{D(i,j) - \theta_{min}}{90° - \theta_{min}}\right) * 100, & D(i,j) > \theta_{min} \end{cases}$$

where θ_{min} is a threshold for minimum angle difference to consider.

11.6 Global orientation quality score

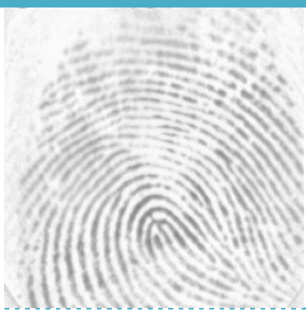
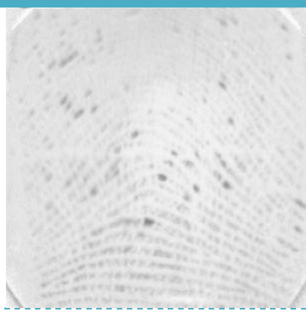
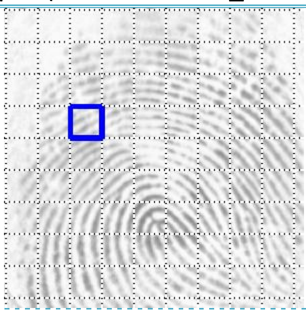
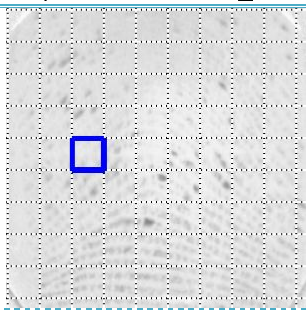
With $N * M$ local orientation quality score blocks the global orientation quality score is computed as:

$$Q_{OF} = \frac{1}{N * M} \sum_{i=1}^{N} \sum_{j=1}^{M} Q_{loc}(i,j)$$

11.7 Notes

In ISO/IEC TR 29794-4:2010 $\theta_{min}$is a constant such that the angular tolerance is 8° ($\theta_{min} = 8$). The local orientation quality score is here assigned such that $Q_{loc}(i,j) = 100$ when the local quality is the highest. This is opposite behavior of the ISO/IEC TR 29794-4:2010 definition where $Q_{loc}(i,j) = 0$ when the local quality is the highest.

11.8 Processing steps

Processing steps for Orientation Flow	
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Current block marked	

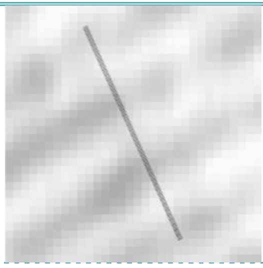
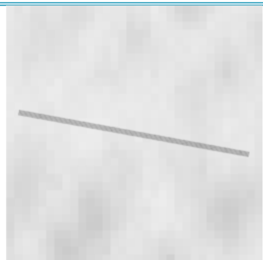
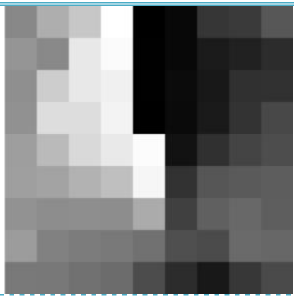
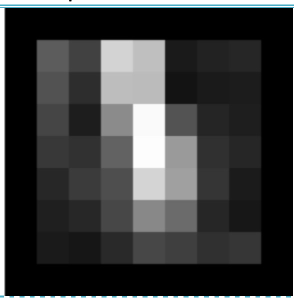
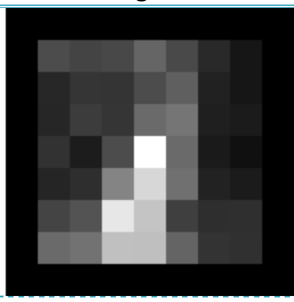
Processing steps for Orientation Flow	
	
Zoomed view of current block	
	
Orientation line shown perpendicular to ridge flow	
	
Block orientations. Black grey values correspond to zero orientation.	
	
Map of differences between a block orientation and its 8-neighborhood	
	
Final flow map	

Table 11-3. Visualization of processing steps in Orientation Flow.

12 Orientation Certainty Level

Quality Feature Summary	
Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.2.2.1
NFIQ 2.0 Identifier	OCL_#
Acronyms	OCL

Table 12-1. Orientation Certainty Level summary.

12.1 Feature Description

Orientation Certainty Level is a measure of the strength of the energy concentration along the dominant ridge flow orientation. The feature operates in a block-wise manner.

12.2 Variables

Name	Default	Description
I	-	Input image.
B_h	32	Block height in pixels.
B_w	32	Block width in pixels.
I_{mask}	-	Segmentation mask.

Table 12-2. Orientation Certainty input variables.

12.3 Algorithm

12.a Compute the block wise intensity gradient by applying the 3x3 Sobel operators.
12.b Compute the covariance matrix.
12.c Compute the eigen values to obtain OCL for each block.
12.d Final score is the mean value of the block OCL values.

12.4 Computing the covariance matrix

The covariance matrix C is computed as:

$$C = \frac{1}{N}\sum_{N}\left\{\begin{bmatrix} dx \\ dy \end{bmatrix}\begin{bmatrix} dx & dy \end{bmatrix}\right\} = \begin{bmatrix} a & c \\ c & d \end{bmatrix}$$

where dx and dy represent the intensity gradient at that pixel and N is $B_h \times B_w$, i.e. the number of pixels per block.

12.5 Computing the eigenvalues and local orientation certainty

From the covariance matrix C the eigenvalues λ_{min} and λ_{max} are computed as:

$$\lambda_{min} = \frac{a + b - \sqrt{(a-b)^2 + 4c^2}}{2}$$

$$\lambda_{max} = \frac{a + b + \sqrt{(a-b)^2 + 4c^2}}{2}$$

this yields an orientation certainty level OCL:

$$OCL = 1 - \frac{\lambda_{min}}{\lambda_{max}}$$

which is a ratio in the interval $[0,1]$ where 1 is highest certainty level and 0 is lowest.

12.6 Computing the quality score

The quality feature Q_{OCL} is compute using the local orientation certainty levels as:

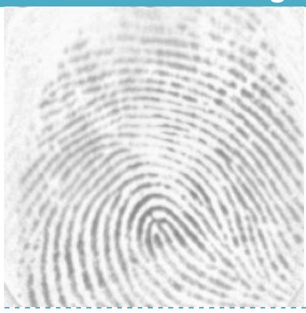
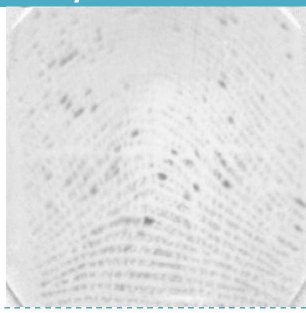
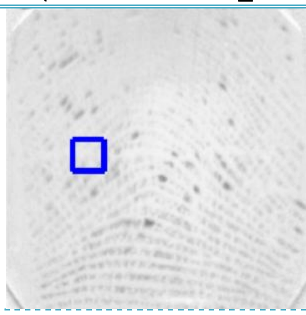
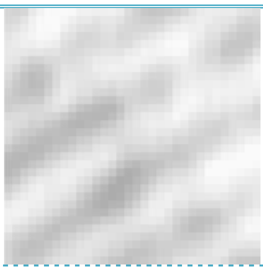
$$Q_{OCL} = \frac{1}{N_b} \sum_{i=1}^{N_b} b_i$$

where N_b is the number of blocks.

12.7 Notes

The computation of the orientation certainty level deviates from ISO/IEC 29794-4:2010 in that we subtract the ratio between the eigen values from 1 such that $OCL = 0$ reflects the lowest quality and $OCL = 1$ the highest quality.

12.8 Processing steps

Processing steps for Orientation Certainty Level	
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Input with current block marked	
	
Zoomed view of block	

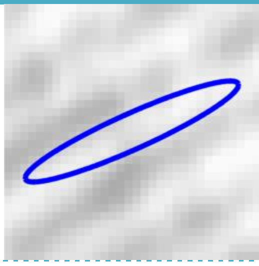
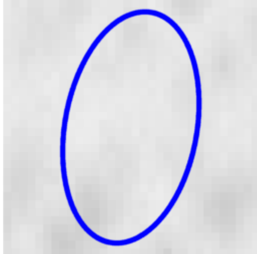
Processing steps for Orientation Certainty Level	
	
Ridge orientation indicated as an ellipse. The eccentricity of the ellipse corresponds to the orientation certainty.	
	
Orientation certainty level in each block. High intensity corresponds to high level of certainty.	

Table 12-3. Visualization of processing steps in Orientation Certainty Level.

13 Radial Power Spectrum

Quality Feature Summary	
Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.3.2.3
NFIQ 2.0 Identifier	PS_#
Acronyms	RPS, POW, Radial Power Spectrum

Table 13-1. Radial Power Spectrum summary.

13.1 Feature Description

The Radial Power Spectrum is a measure of maximal signal power in a defined frequency band of the global radial Fourier spectrum. Ridges can be locally approximated by means of a single sine wave, hence high energy concentration a narrow frequency band corresponds to consistent ridge structures.

13.2 Variables

Name	Default	Description
r_{min}	25	Lower bound of frequency band
r_{max}	84	Upper bound of frequency band
Δ_r	30	Sampling step between annular bands in the frequency spectrum
θ	180	Degrees of the spectrum to consider

Table 13-2. Radial Power Spectrum input variables.

13.3 Algorithm

13.a Compute the magnitude of the 2D-DFT $F(u,v)$

13.b Transform $F(u,v)$ into polar coordinates and normalize to the range of [0,1]

13.c Determine the maximum energy to compute Q_{pow}

13.4 The 2D Discrete Fourier Transform

The 2D discrete Fourier transform $F(u,v)$ of $I(x,y)$ is:

$$F(u,v) = \frac{1}{X \times Y} \sum_{x=0}^{X-1} \sum_{y=0}^{Y-1} I(x,y) \exp\left(-j2\pi\left(\frac{m*x}{X} + \frac{n*y}{Y}\right)\right)$$

and the magnitude of $F(u,v)$ is:

$$A(F(u,v)) = |F(u,v)|^2$$

13.5 Magnitude of frequency bands polar coordinates

The magnitude of the annular band between r and Δ_r in the polar Fourier spectrum $F(\alpha,r)$ is computed as:

$$J(r) = \frac{\sum_{\alpha=0}^{\pi} \sum_{r}^{r+\Delta_r} F(\alpha,r)}{\sum_{\alpha=0}^{\pi} \sum_{r_{min}}^{r_{max}} F(\alpha,r)}$$

where α is the angle and r is the radius.

13.6 Determine quality score from energy distribution

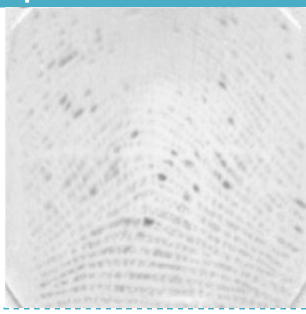
The quality feature Q_{POW} is found as:

$$Q_{POW} = \max_{r \in [\Delta r]} |J(r)|$$

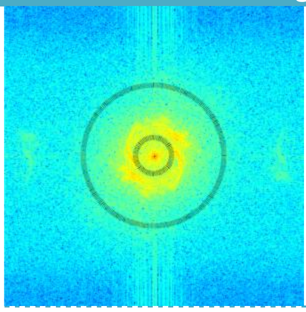
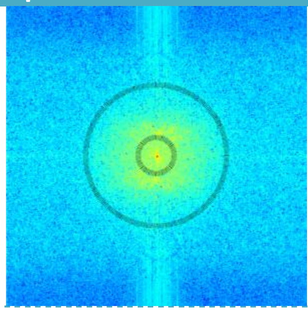
13.7 Notes

The Radial Power Spectrum quality feature is resolution dependant. The given defaults assume 500ppi.

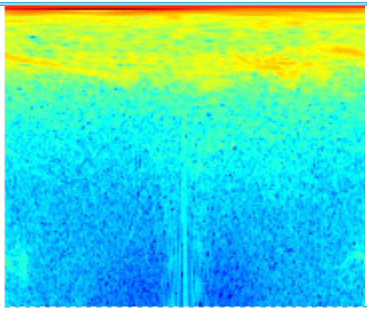
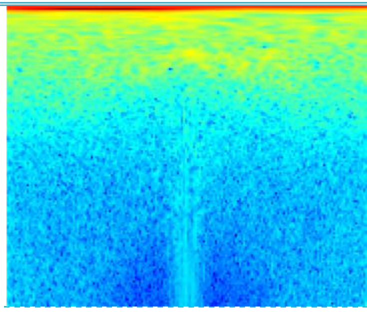
13.8 Processing steps

Processing steps for Radial Power Spectrum	
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)

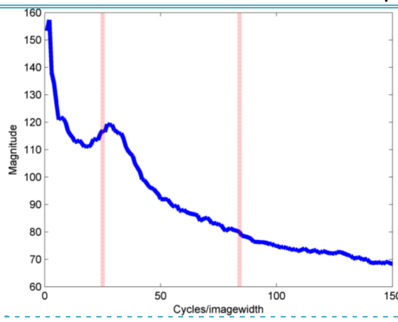
Processing steps for Radial Power Spectrum

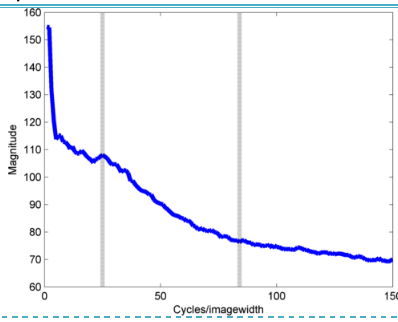



Spectrum with the frequency band of interest located between the

Polar representation of the spectrum





Spectrum with marked frequency of interest

Table 13-3. Visualization of processing steps in Radial Power Spectrum.

14 Ridge Valley Uniformity

Quality Feature Summary	
Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.2.2.4
NFIQ 2.0 Identifier	RVU_#
Acronyms	RVU

Table 14-1. Ridge Valley Uniformity summary.

14.1 Feature Description

Ridge Valley Uniformity is a measure of the consistency of the ridge and valley widths.

14.2 Variables

Name	Default	Description
I	-	Input image
B_h	32	Block height in pixels
B_w	32	Block width in pixels
I_{mask}	-	Segmentation mask

Table 14-2. Ridge Valley Uniformity input variables.

14.3 Algorithm

14.a For each block V_0 in the image determine the dominant ridge flow orientation to create an orientation line which is perpendicular to the ridge flow

14.b Align V_0 such that the orientation line is horizontal to create V_1

14.c From V_1 extract a block V_2 which is centered around the orientation line

14.d Compute the average profile V_3 of V_2 to produce a vector

14.e Determine a threshold DT by applying linear regression on V_3

14.f Segment V_3 into two levels based on the threshold DT

14.g Determine the indexes in V_3 where a change from background to foreground or foreground to background occurs. If no changes are found then return an empty ratio for that block.

14.h Remove the first and last parts of V_3 to remove incomplete ridge/valleys occurring at the border of the original block. Likewise remove the corresponding changes from the change index vector.

14.i If there are no changes after step 8, return an empty ratio for that block

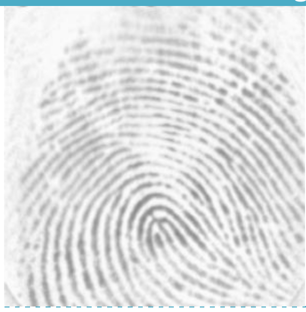
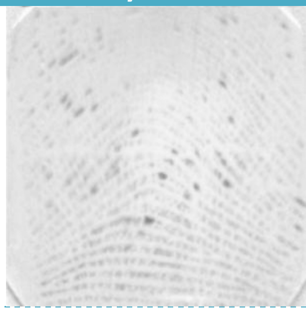
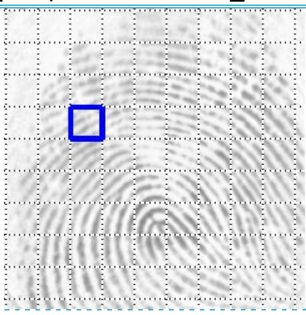
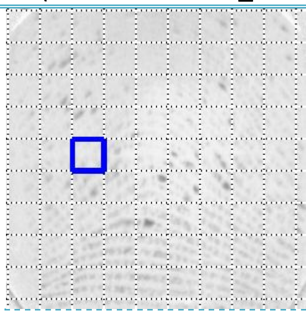
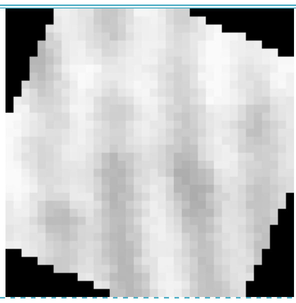
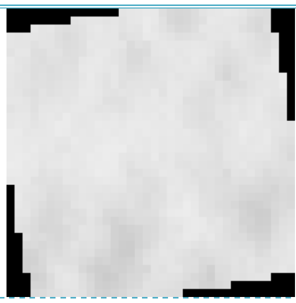
14.j Calculate the ratios between the width of ridges and valleys for the block.

14.k Obtain the final quality score as the standard deviation of all ratios.

14.4 Notes

The Ridge Valley Uniformity quality feature is resolution dependent. The given defaults assume 500ppi.

14.5 Processing steps

Processing steps for Ridge Valley Uniformity	
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Input with block grid and current block marked	
	
Current block	
	
Current block with overlap	
	
Block rotated so ridge lines are vertical	

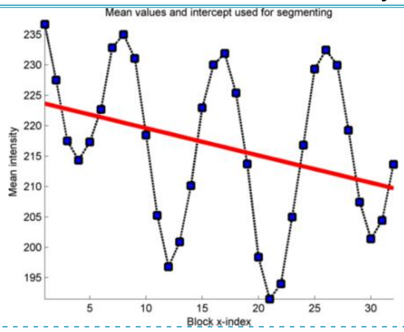
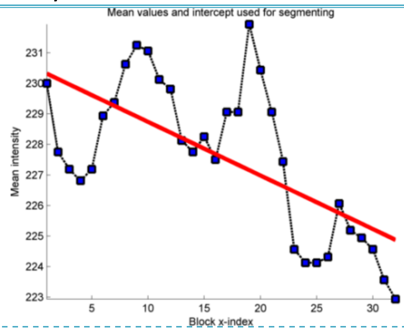
Processing steps for Ridge Valley Uniformity	
	
Cropped section of block	
Projection of mean intensity	
	
Profile of mean intensity with threshold marked.	
Segmentation according to thresholding. Ridges marked in black, valleys in white	
Location of ridge-valley edges marked with white	
Cleaned ridge-valley segmentation contains only complete ridges and valleys.	

Table 14-3. Visualization of processing steps in Ridge Valley Uniformity.

15 Sigma Mu Block

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	SMB_#
Acronyms	SMB

Table 15-1. Sigma Mu Block summary.

15.1 Feature Description

Sigma Mu Block is the standard deviation of the block wise mean pixel intensity value in the input image.

15.2 Variables

Name	Default	Description
I	-	Input image.
B_h	32	Block height in pixels.
B_w	32	Block width in pixels.

Table 15-2. Sigma Mu Block summary.

15.3 Algorithm

15.a Compute the mean intensity for each block in I.
15.b Compute the standard deviation of the mean intensities.

16 Sigma

Quality Feature Summary	
Origin	
NFIQ 2.0 Identifier	Sigma_#
Acronyms	SIG

Table 16-1. Sigma summary.

16.1 Feature Description

Sigma is the standard deviation of pixel intensity values in the input image.

16.2 Variables

Name	Default	Description
I	-	Input image.

Table 16-2. Sigma input variables.

16.3 Algorithm

16.a Compute the standard deviation of the pixel intensities in I.

17 References

Daugman John Uncertainty relation for resolution in space,spatial frequency, and orientation optimed by two-dimensional visual cortical filters [Tidsskrift]. - [s.l.] : J. Opt. Soc. Am. A, 1985. - Årg. 2.

ISO/IEC 29794-4 TR Information technology - Biometric sample quality - Part 4: Finger image data [Rapport]. - 2010.

Olsen Martin Aastrup, Xu Haiyun og Busch Christoph Gabor Filters as Candidate Quality Measure for NFIQ 2.0 [Konference] // Proceedings of the 5th IAPR International Conference on Biometrics (ICB 2012). - 2012.

Shen LinLin, Kot Alex ChiChung og Koo Wai Mun Quality measures of fingerprint images [Konference] // AVBPA. - 2001.