Development of NFIQ 2.0

Quality Feature Definitions

Version 0.4

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

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Notation

X	Image width in pixels (horizontal)
Y	Image height in pixels (vertical)
$I(x,y)$	Image location where $I(1,1)$ denotes the pixel in the upper left corner
M	Number of blocks horizontally
N	Number of blocks vertically
$V(i,j)$	Image block where $V(1,1)$ denotes the block in the upper left corner

Frequency Domain Analysis

Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) – Clause 6.2.2.3
NFIQ2.0 identifier	FDA_#
Short acronym	

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.

Variables

Variables description and default values for 500 ppi images.

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

Extracting the ridge-valley signature

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

Computing the Frequency Domain Analysis score

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

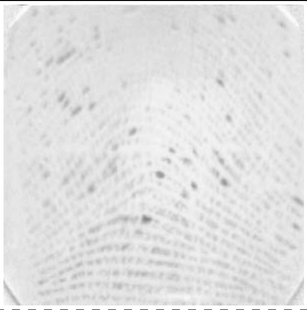
Algorithm

1. For each block of size $B_h * B_w$ determine the dominant ridge flow orientation
2. Rotate the block such that the dominant ridge flow is perpendicular to the x-axis
3. Crop regions of block such that no invalid regions are included in the block
4. Calculate the mean pixel intensity value $T(x)$ for the block to extract the ridge-valley structure
5. Calculate the Fourier spectrum of $T(x)$
6. Discard the DC component of $T(x)$ and determine the term F_{max} with the highest magnitude $A(F_{\max})$
7. The final Frequency Domain Analysis score is the mean of scores assigned to foreground blocks as defined by I_{mask}.

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 $Q_{FDA} = 1$.

Processing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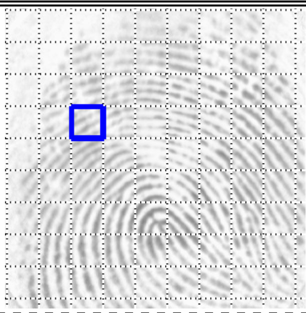
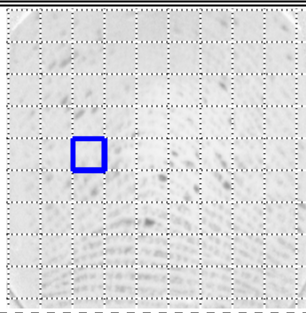
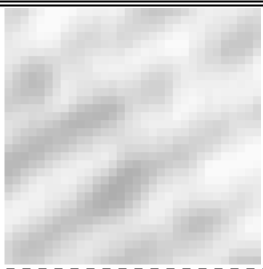
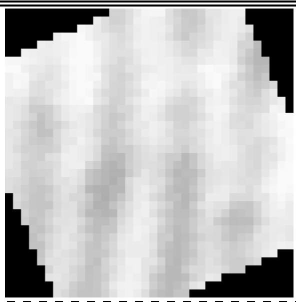
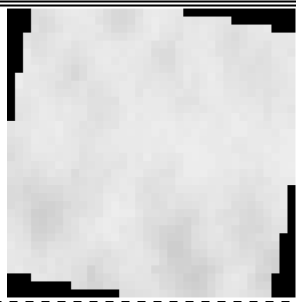
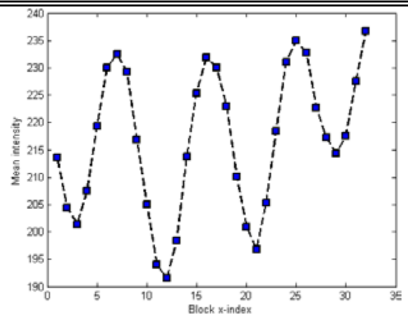
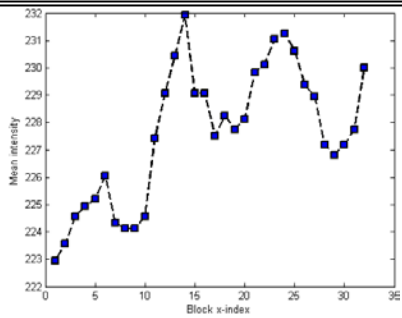
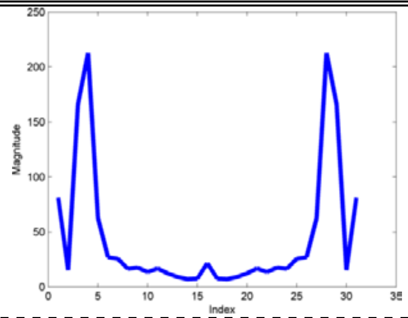
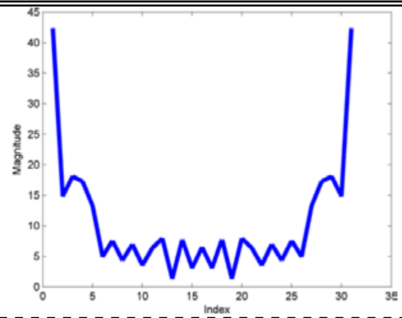
	
Input with block grid and current block marked in blue	
	
Zoomed view of current block	
	
Block rotated	
	
Block cropped	



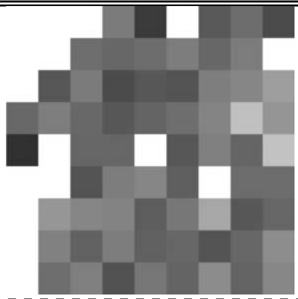


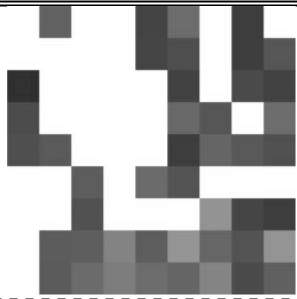
Block mean intensity values





Block DFT





Map of FDA quality values

Gabor

Origin	Olsen, Xu, Busch, Gabor Filters as Candidate Quality Measure for NFIQ 2.0 in ICB 2012
NFIQ2.0 identifier	GABOR_#
Short acronym	GAB

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 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.

Variables

Variables description and default values for 500 ppi images.

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

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

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

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 by σ_x,σ_y.

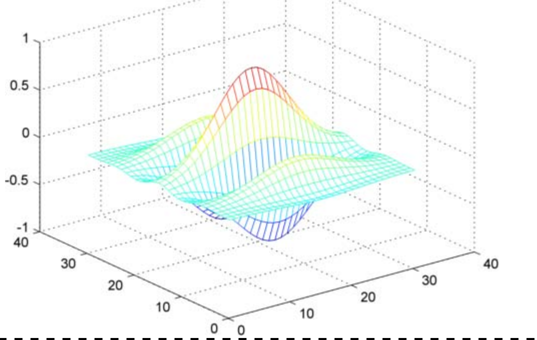
The filter bank size *n* is used to compute the differently oriented Gabor filters composing the filter bank. The computation of θ given *n* is as follows:

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

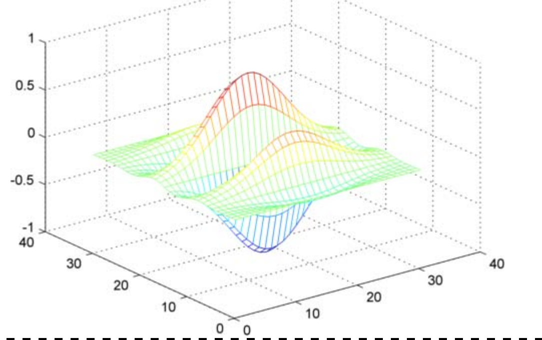
Algorithm

1. Convolve input image with a 2D Gaussian kernel with $\sigma = 1$ and subtract it from the input image to give $\bar{I}$
2. Compute the Gabor response of $\bar{I}$ for each orientation θ
3. Convolve the magnitude (complex modulus) of each Gabor response with a 2D Gaussian kernel with $\sigma = 4$
4. Compute the standard deviation of the Gabor magnitude response values at each location yielding a map of standard deviations.
5. Sum the map of standard deviations and normalize according to number of sample points (typically image size) to produce the final Gabor quality score.

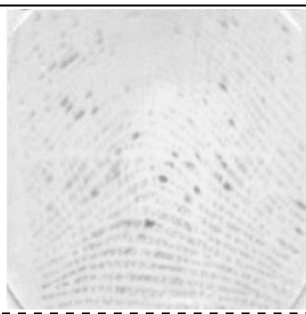
Processing



Real part of Gabor filter



Imaginary part of Gabor filter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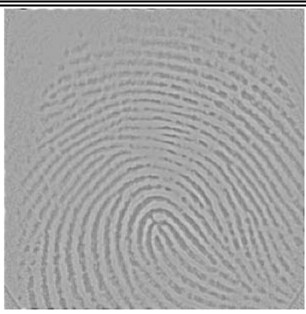
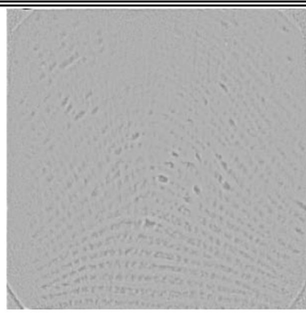
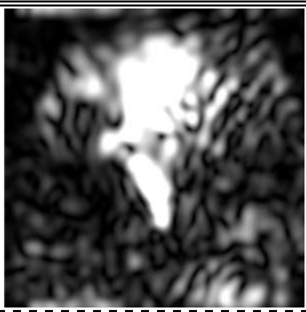
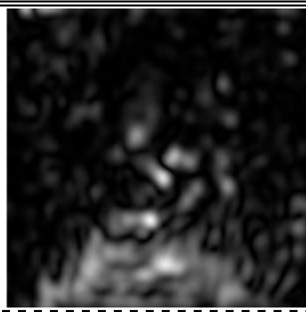
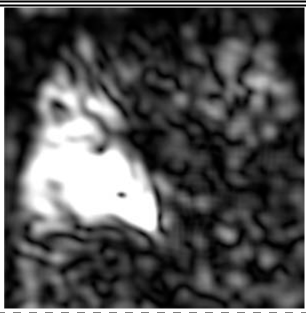
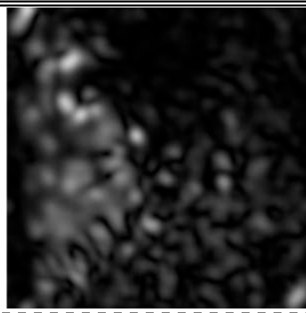
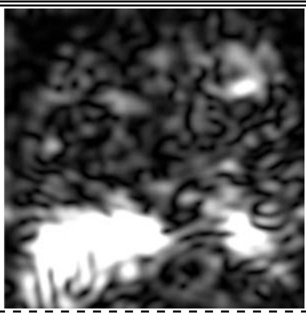
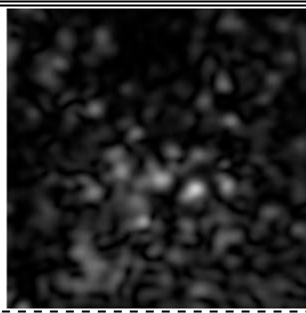
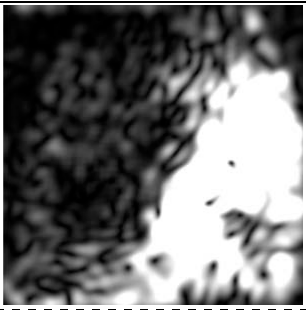
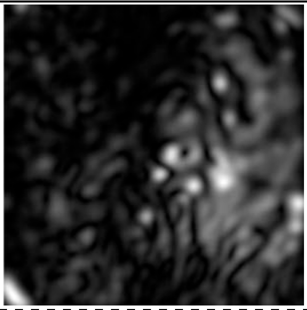
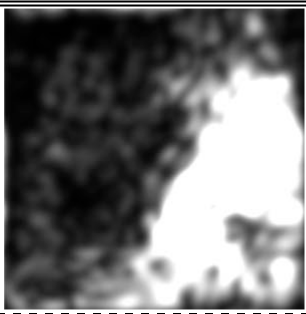
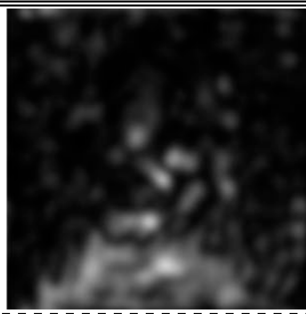
	
Subtraction of image convolved with Gaussian.	
	
Gabor response for filtered image at orientation 0	
	
Gabor response for filtered image at orientation 1/4	
	

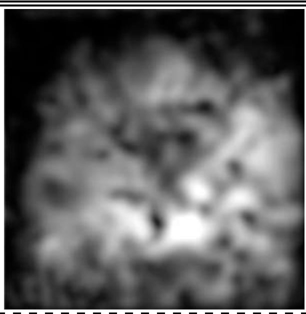
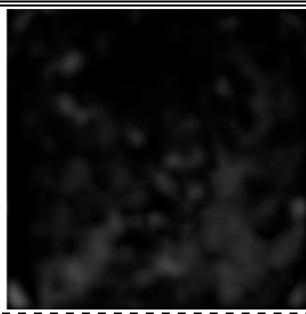
Gabor response for filtered image at orientation 2/4

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

Gabor Segment

Origin	
NFIQ2.0 identifier	GS_#
Short acronym and alternate identifier	GSG, GaborSeg

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 segmentation to 2 levels is applied before computing the final quality score.

Variables

Variables description and default values for 500 ppi images.

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

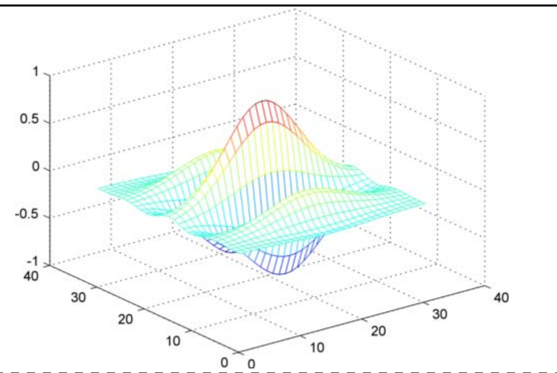
Segment to two levels

Segmenting 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.

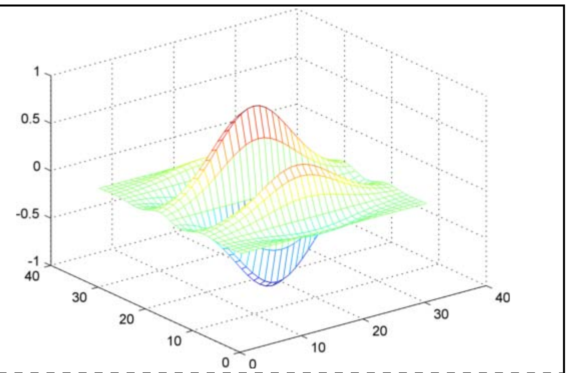
Algorithm

1. Convolve input image with a 2D Gaussian kernel with $\sigma = 8$
2. Compute the Gabor response of the image for each orientation
3. Convolve the magnitude (complex modulus) of each Gabor response with a 2D Gaussian kernel with $\sigma = 4$
4. Compute the standard deviation of the Gabor magnitude response values at each location yielding a map of standard deviations.
5. Segment the standard deviation map into two levels.
6. Sum the map standard deviations and normalize according to number of sample points (typically image size) to produce the final Gabor quality score.

Processing

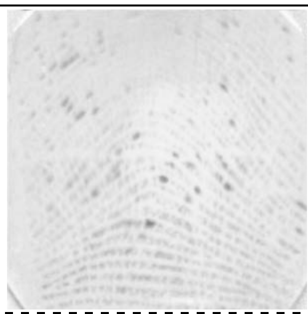


Real part of Gabor filter

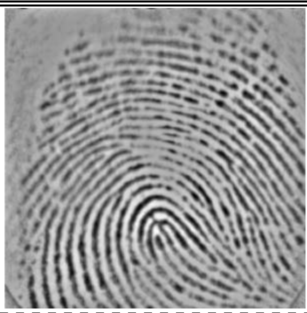
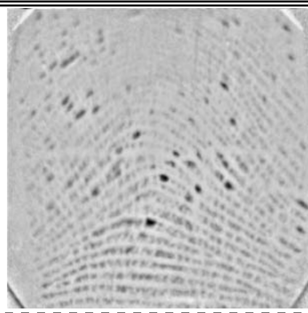


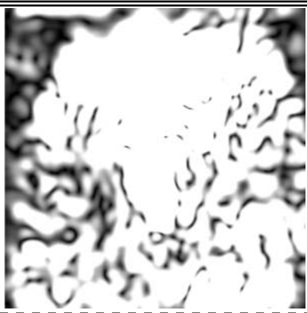
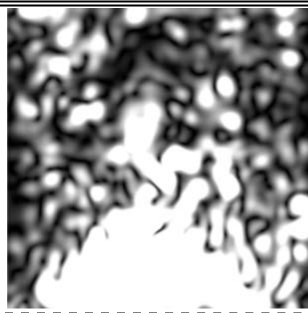
Imaginary part of Gabor filter

Input (FVC2000Db1 1_1.bmp)

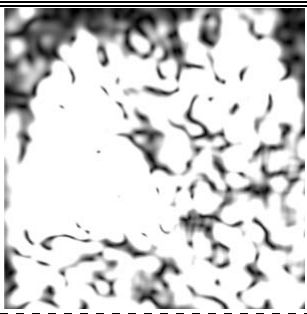
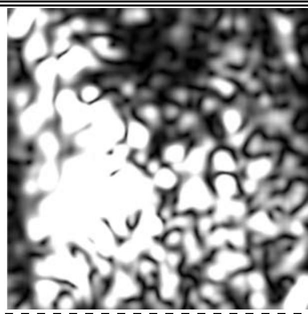


Input (FVC200Db1 100_1.bmp)

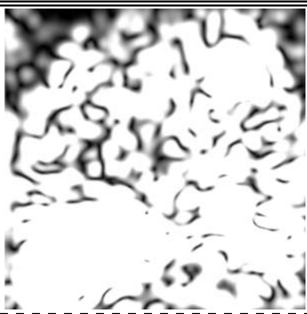
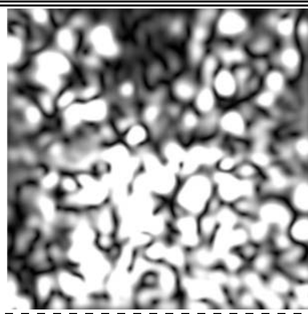



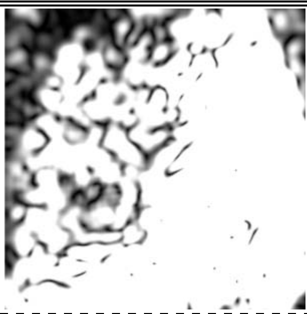
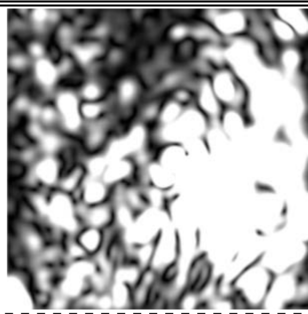
Gabor response at orientation 0

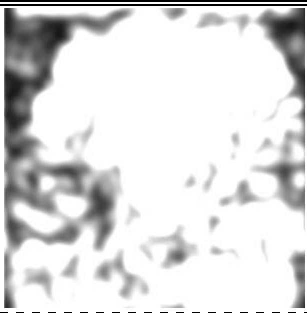
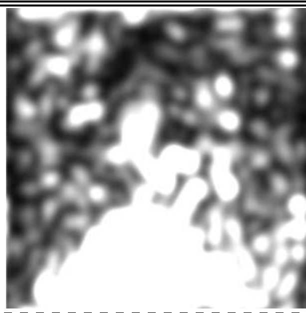
Gabor response at orientation 1/4

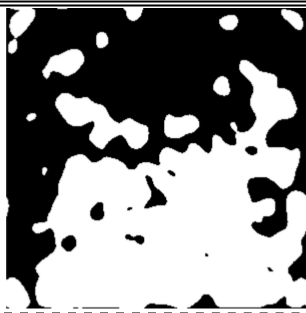
Gabor response at orientation 2/4

Gabor response at orientation 3/4

Standard deviation of filter responses

Segmentation of standard deviation of filter responses into two levels

Gabor Shen

Origin	L. Shen, A. C. Kot, and W. M. Koo. Quality measures of fingerprint images. In AVBPA, 2001
NFIQ2.0 identifier	GSh_#
Short acronym	GSH

Description

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

Variables

Variables description and default values for 500 ppi images.

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

Algorithm

1. Compute the Gabor response of $\bar{I}$ for each orientation θ
2. Computed the standard deviation of the Gabor magnitude response values at each location yielding a map of standard deviations.
3. Divide the map of standard deviations into blocks of size $b * b$
4. Compute the mean value of each block μ_i
5. Determine the set of blocks, V_F, belonging to the foreground as those where $\mu_i > T_b$
6. Determine the set of blocks, V_P, which are of poor quality as those where $(\mu_i > T_b) \wedge (\mu_i < T_q)$

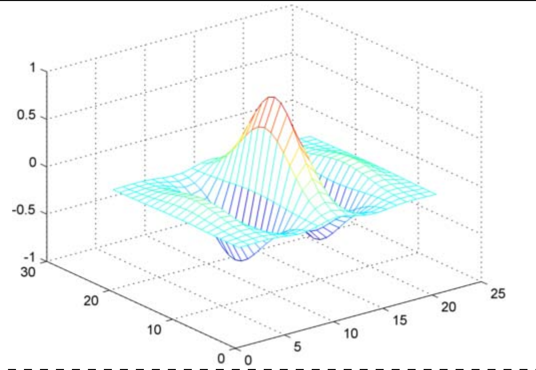
7. The final score $Q_{GABORSHEN}$ is determined as the ratio between V_F and V_P.

Recommendations
Suggested by Shen et. al.:

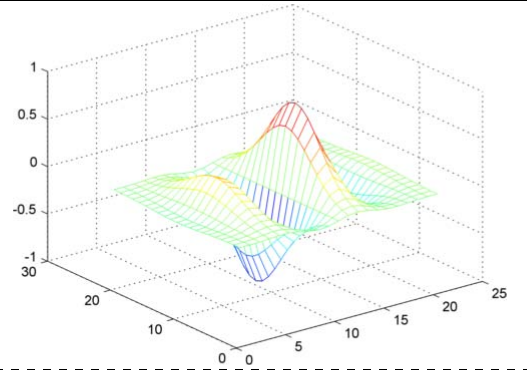
$$\sigma_x = \sigma_y = 4$$
$$f = 0.12$$
$$n = 8$$
$$b = 30$$

T_b and T_q are manually determined according to dataset.

Processing



Real part of Gabor filter



Imaginary part of Gabor filter

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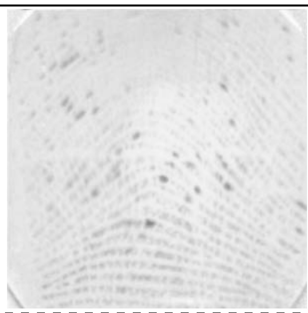
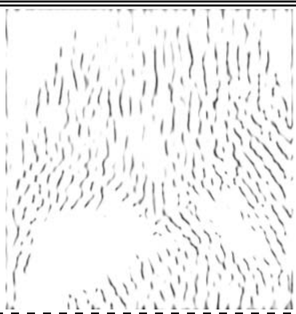
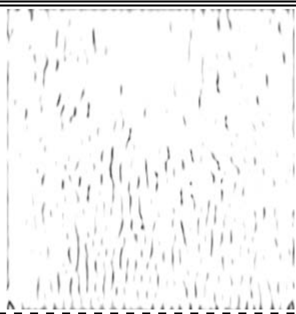
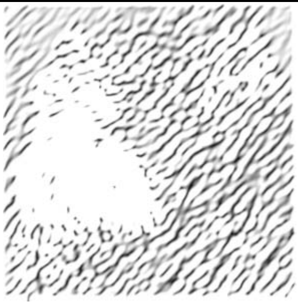
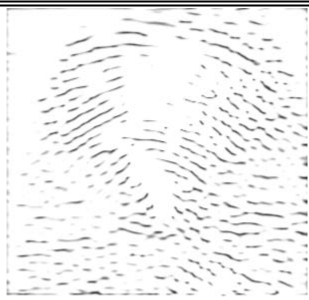
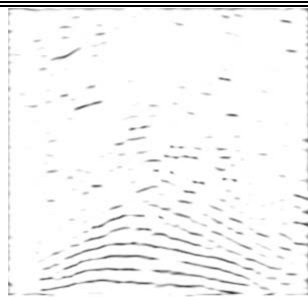
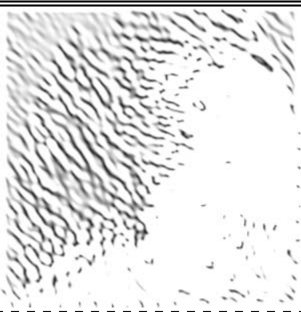
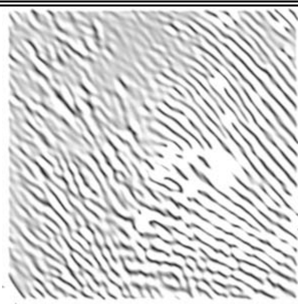
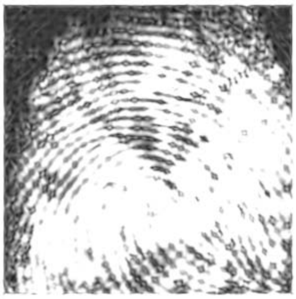
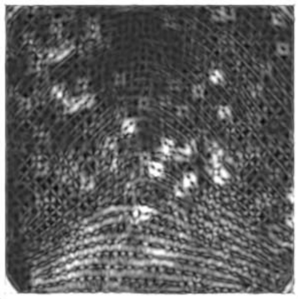
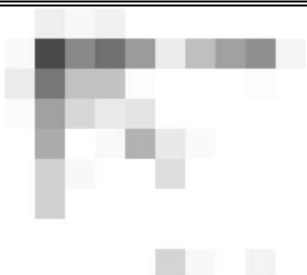


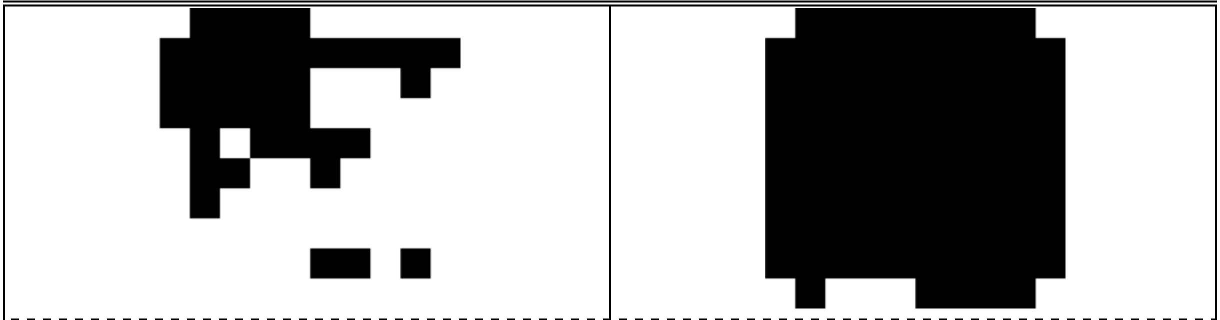
Input (FVC200Db1 100_1.bmp)



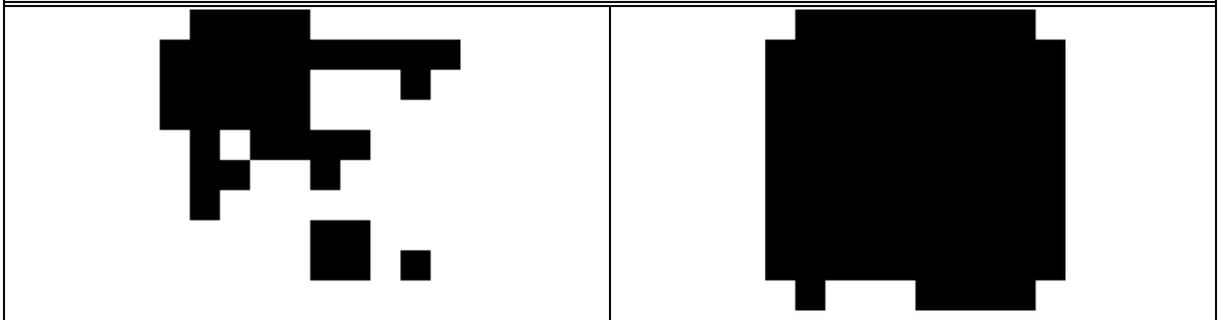


Gabor response at orientation 0

	
Gabor response at orientation 1/4	
	
Gabor response at orientation 2/4	
	
Gabor response at orientation 3/4	
	
Standard deviation of filter responses	
	
Blockwise mean of filter responses	



Foreground blocks



Blocks marked as poor

Local Clarity Score

Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) – Clause 6.2.2.2
NFIQ2.0 identifier	LCS_#
Short acronym and alternate identifier	LCS, Ridge-valley Structure

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.

Variables

Variables description and default values for 500 ppi images.

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

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.

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.

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

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 [] $W^{max} = 5$ is reasonable for 125 dpi resolution.

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.

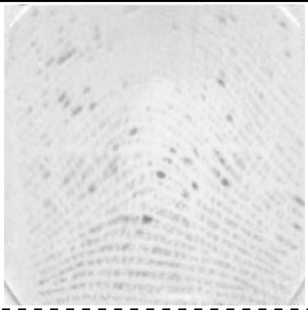
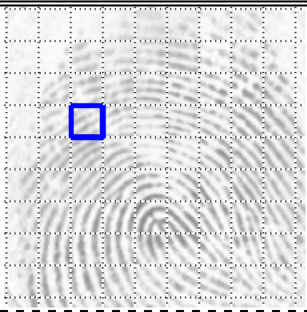
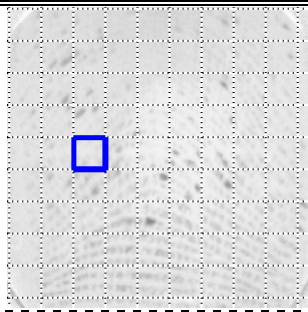
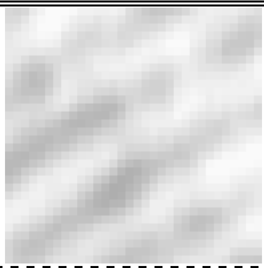
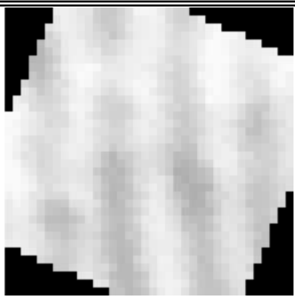
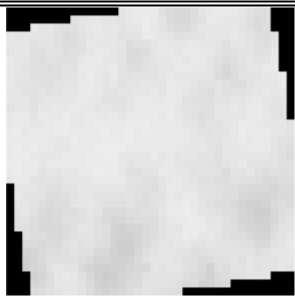
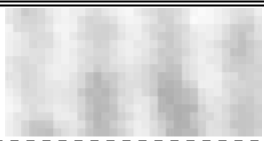
Algorithm

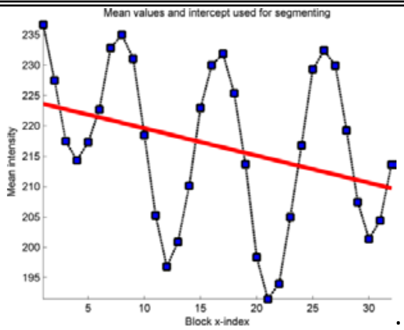
1. For each block V_0 in the image determine the dominant ridge flow orientation to create an orientation line which is perpendicular to the ridge flow
2. Align V_0 such that the orientation line is horizontal to create V_1
3. From V_1 extract a block V_2 which is centered around the orientation line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

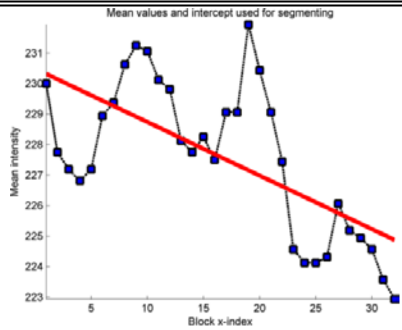
Further Comments

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

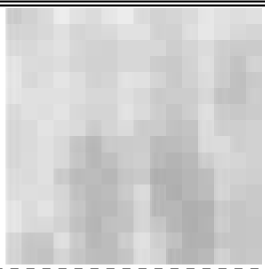
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)
	
Input with grid and block marked in blue	
	
Zoomed view of block	
	
Block rotated to align ridgelines vertically	
	
Extracted section of the block	
Projected mean gray intensity values	



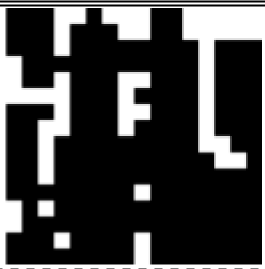
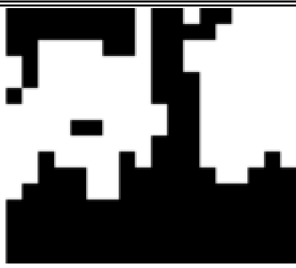


Ridge-valley profile as found by mean values. Red line indicates the threshold for ridge-valley separation

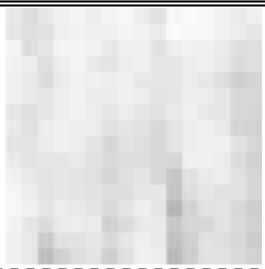
Ridge-valley segmentation. Ridges shown in black, valleys in white. The mean intensity values are shown above for comparison.



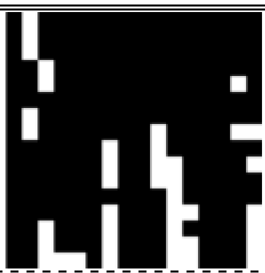
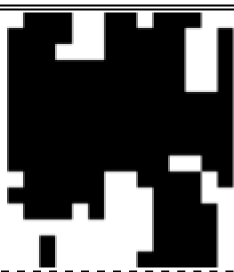
Ridge areas composed into one block.

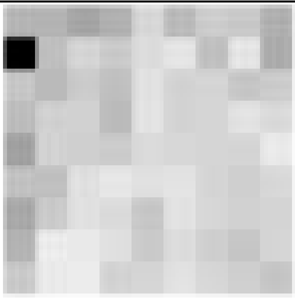
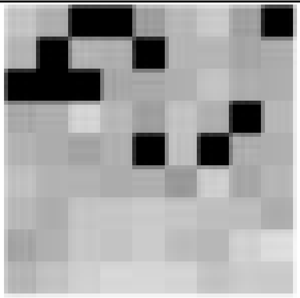



Shown in white are the parts of the fingerprint which were determined to be ridge but do not belong to ridge as defined by the threshold.



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.	
	
Map of local clarity scores. High intensity corresponds to high local clarity.	

Mu

Origin	
NFIQ2.0 identifier	Mu_#
Short acronym	MUQ

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

Variables
Variables description and default values for 500 ppi images.

Name	Default	Description
I	-	Input image

Algorithm

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

Mu Mu Block

Origin	
NFIQ2.0 identifier	MMB_#
Short acronym	MMB

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

Variables
Variables description and default values for 500 ppi images.

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

Mu Mu Sigma Block

Origin	
NFIQ2.0 identifier	MMSB_#
Short acronym	MMSB

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.

Variables
Variables description and default values for 500 ppi images.

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

Mu Sigma Block

Origin	
NFIQ2.0 identifier	MSB_#
Short acronym	MSB

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

Variables
Variables description and default values for 500 ppi images.

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

Orientation Certainty Level

Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.2.2.1
NFIQ2.0 identifier	OCL_#
Short acronym	OCL

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.

Variables
Variables description and default values for 500 ppi images.

Name	Default	Description
I	-	Input image

B_h	32	Block height in pixels
B_w	32	Block width in pixels
I_{mask}	-	Segmentation mask

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.

Computing the eigenvalues and the final quality score
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.

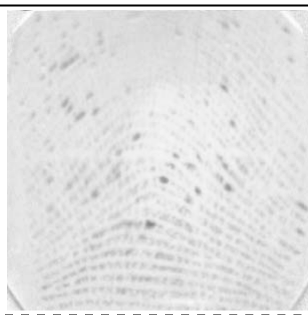
Algorithm
For each block b_i

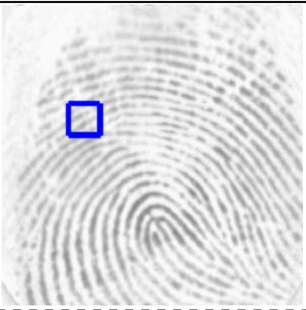
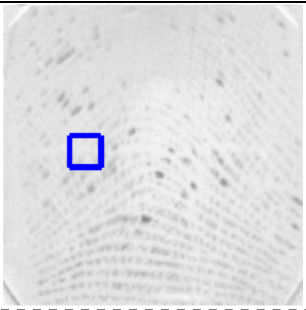
1. Compute the intensity gradient by applying the 3x3 Sobel operators
2. Compute the covariance matrix
3. Compute the eigenvalues to obtain OCL

Finally compute the quality measure Q_{OCL} as:

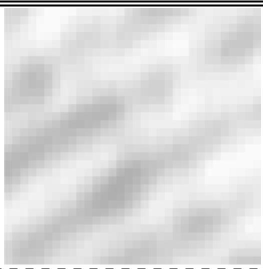
$$Q_{OCL} = \frac{1}{B}\sum_{i=1}^{B} b_i$$

Processing

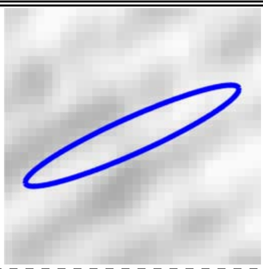
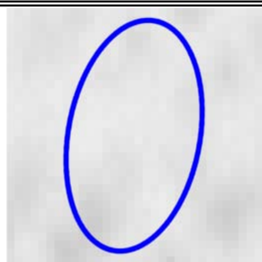
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)

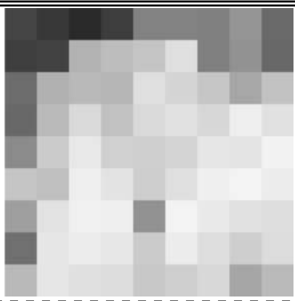
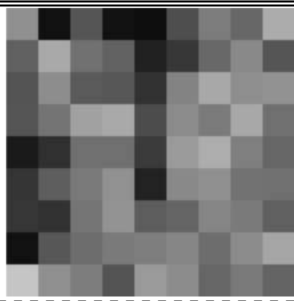
Input with current block marked



Zoomed view of block

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.

Orientation Flow

Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.3.2.1
NFIQ2.0 identifier	OF_#
Short acronym	OF

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.

Variables

Variables description and default values for 500 ppi images.

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	Minimum angle difference to consider when computing the quality score

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:

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

Local orientation quality score

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

$$Q_{loc}(i,j) = \begin{cases} 100 & , \quad D(i,j) \le \theta_{min} \\ \left(1 - \frac{D(i,j) - 8}{90 - 8}\right) * 100, & \quad D(i,j) > \theta_{min} \end{cases}$$

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

Global orientation quality score

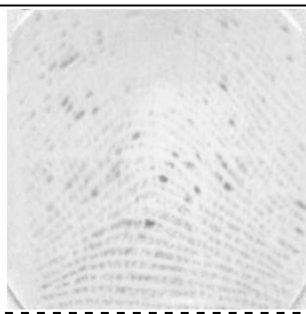
With $N * M$ local orientation quality score blocks the global orientation quality score is computed as:

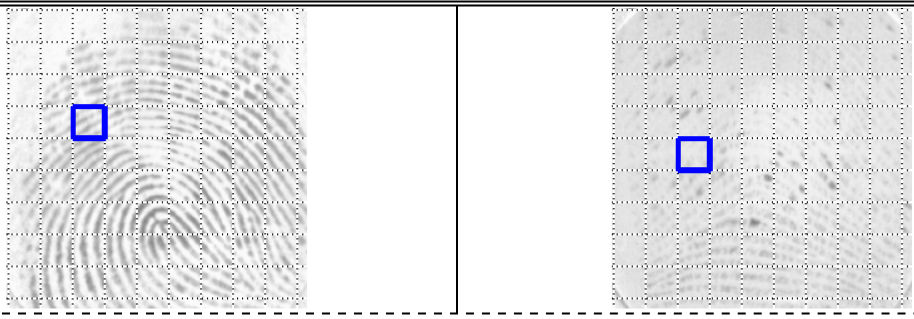
$$Q_{OF} = \frac{1}{N * M}\sum_{i=1}^{N}\sum_{j=1}^{M} Q_{loc}(i,j)$$

Algorithm

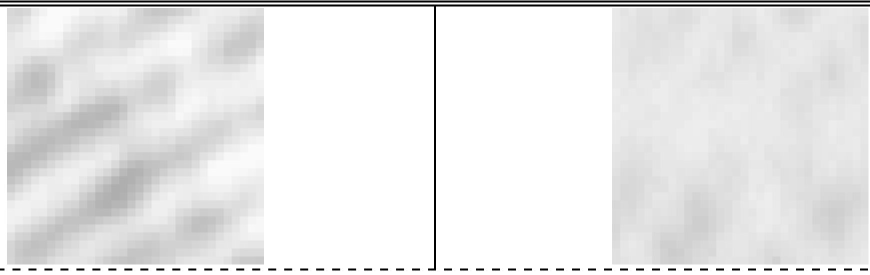
1. Compute the absolute orientation difference $D(i,j)$ for each block $V(i,j)$
2. Compute the local orientation quality score $Q_{loc}(i,j)$ for $D(i,j)$
3. Compute the global orientation flow quality score Q_{OF}

Processing

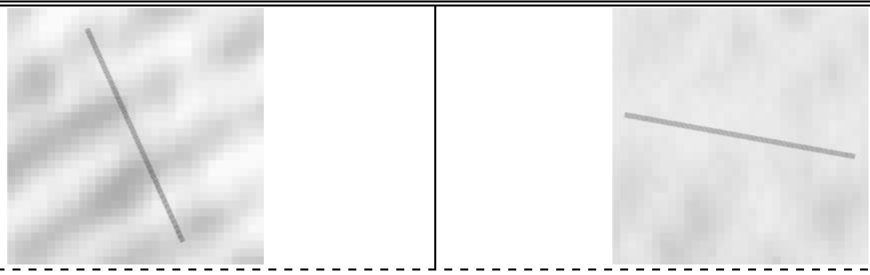
	
Input (FVC2000Db1 1_1.bmp)	Input (FVC200Db1 100_1.bmp)



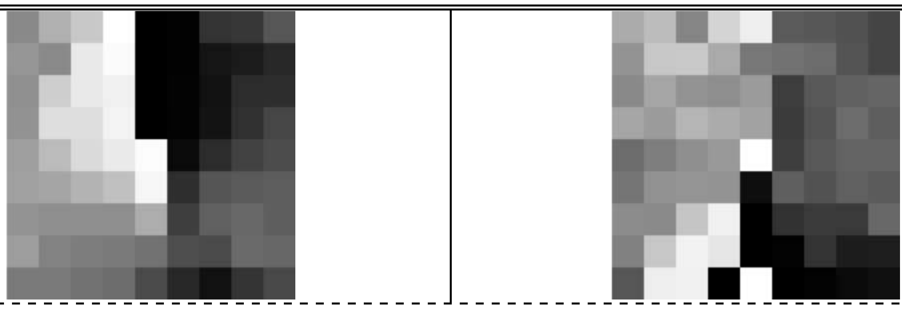
Current block marked



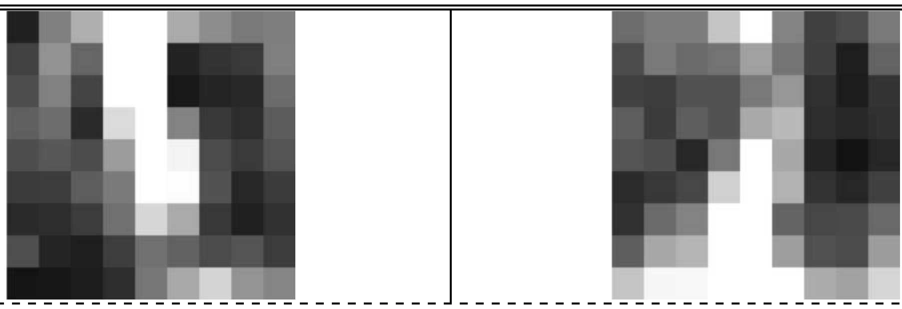
Zoomed view of current block



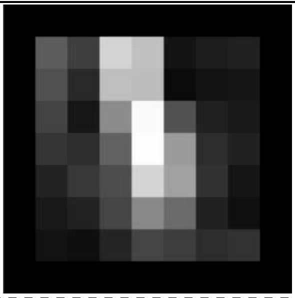
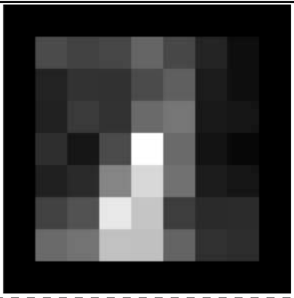
Orientation line shown perpendicular to ridges.



Block orientations



Map of differences between a block orientation and its 8-neighborhood

	
Final flow map	

Radial Power Spectrum

Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.3.2.3
NFIQ2.0 identifier	PS_#
Short acronym and alternate identifier	RPS, POW, Radial Power Spectrum

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.

Variables
Variables description and default values for 500 ppi images.

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

The 2D Discrete Fourier Transform
The 2D discrete Fourier transform $f(x, y)$ of $I(x, y)$ is:

$$f(x,y) = \frac{1}{M * N} \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} I(x,y) \exp\left(-j2\pi\left(\frac{m * x}{M} + \frac{n * y}{N}\right)\right)$$

and the magnitude of $f(x,y)$ is:

$$F(x,y) = |f(x,y)|^2$$

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.

Determine quality score from energy distribution

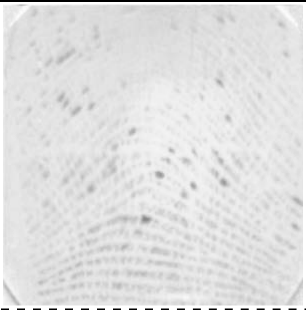
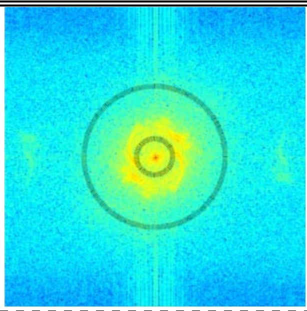
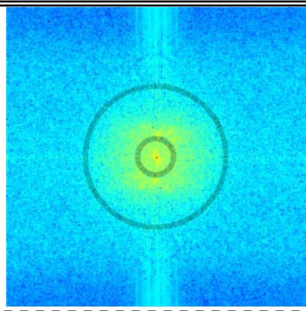
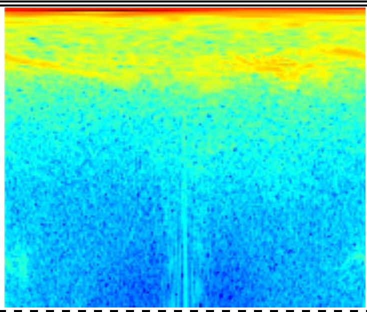
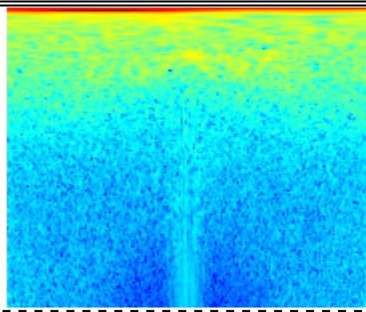
The quality feature Q_{POW} is found as:

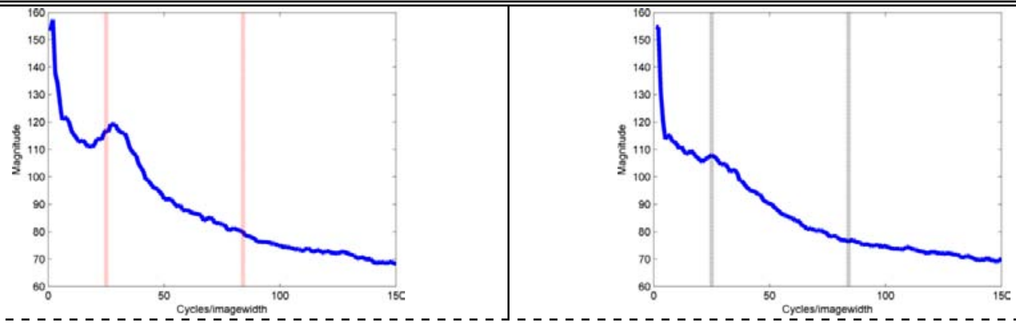
$$Q_{POW} = \max_{r \in [r_{min}, r_{max}]} J(r)$$

Algorithm

1. Compute the magnitude of the 2D-DFT $F(x, y)$
2. Transform $F(x, y)$ into polar coordinates and normalize to the range of $[0,1]$
3. Determine the maximum energy to compute Q_{POW}

Process

<table>
<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">Spectrum with the frequency band of interest located between the</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Polar representation of the spectrum</td></tr>
</table>



Spectrum with marked frequency of interest

Ridge Valley Uniformity

Origin	ISO/IEC TR 29794-4:2010 (ISO/IEC, 2010) - Clause 6.2.2.4
NFIQ2.0 identifier	RVU_#
Short acronym	RVU

Description

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

Variables

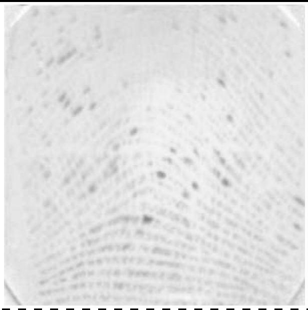
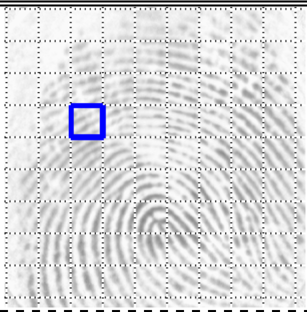
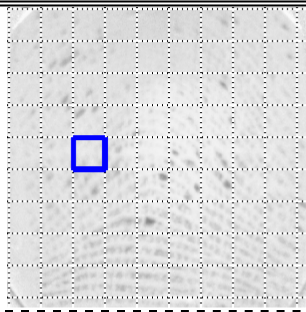
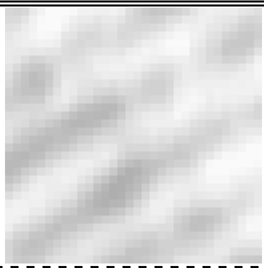
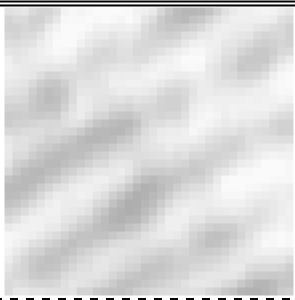
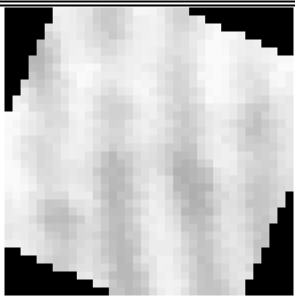
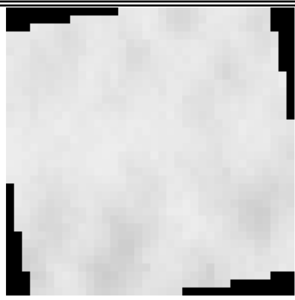
Variables description and default values for 500 ppi images.

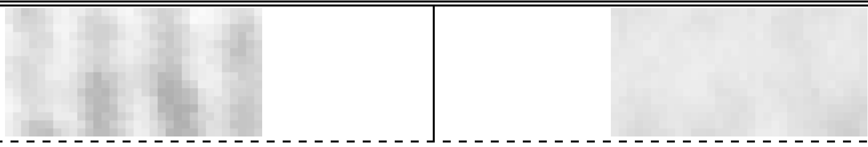
Name	Default	Description
I	-	Input image
B_h	32	Block height in pixels
B_w	32	Block width in pixels
I_{mask}	-	Segmentation mask

Algorithm

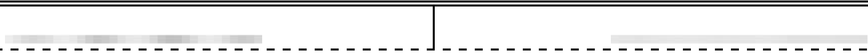
1. For each block V_0 in the image determine the dominant ridge flow orientation to create an orientation line which is perpendicular to the ridge flow
2. Align V_0 such that the orientation line is horizontal to create V_1
3. From V_1 extract a block V_2 which is centered around the orientation line
4. Compute the average profile V_3 of V_2 to produce a vector
5. Determine a threshold DT by applying linear regression on V_3
6. Segment V_3 into two levels based on the threshold DT
7. 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.
8. 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.
9. If there are no changes after step 8, return an empty ratio for that block
10. Calculate the ratios between the width of ridges and valleys for the block.
11. Obtain the final quality score as the standard deviation of all ratios.

Process

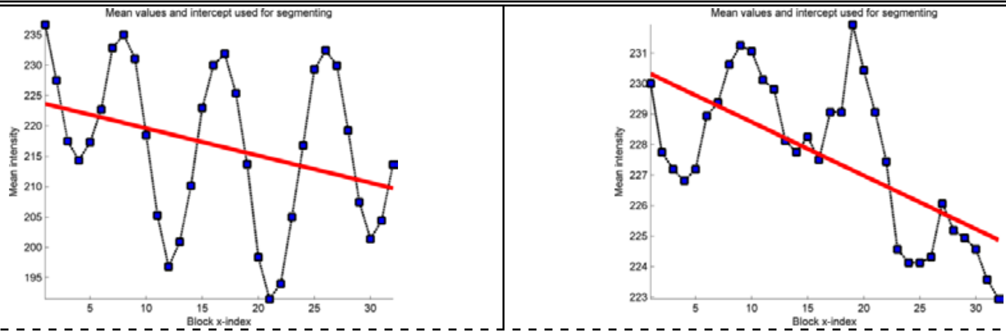
<table>
<tr><td></td><td></td></tr>
<tr><td>Input (FVC2000Db1 1_1.bmp)</td><td>Input (FVC200Db1 100_1.bmp)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Input with block grid and current block marked</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Current block</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Current block with overlap</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Block rotated so ridge lines are vertical</td></tr>
</table>

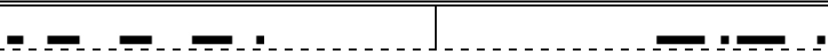


Cropped section of block

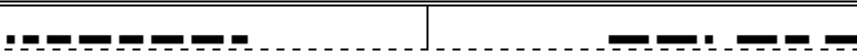


Projection of mean intensity

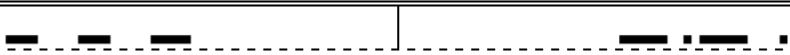




Segmentation according to thresholding. Ridges marked in black, valleys in white



Location of ridge-valley edges marked with white



Cleaned ridge-valley segmentation contains only complete ridges and valleys.

Sigma

Origin	
NFIQ2.0 identifier	Sigma_#
Short acronym	SIG

Description

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

Algorithm

$$Q_{SIGMA} = \left(\frac{1}{X * Y - 1} \sum_{y=1}^{Y} \sum_{x=1}^{X} (I(x,y) - \bar{I})^2 \right)^{\frac{1}{2}}$$

where $\bar{I}$ is the mean pixel intensity of I.

Variables

Variables description and default values for 500 ppi images.

Name	Default	Description
I	-	Input image

Sigma Mu Block

Origin	
NFIQ2.0 identifier	SMB_#
Short acronym	SMB

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

Variables
Variables description and default values for 500 ppi images.

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

References

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

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