Technical University of Denmark

Data Science, Compression and Image Communication

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Wavelet Encoding on Fingerprint Images

Project Description

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1 Introduction

Various law enforcement agencies around the world have very large databases of fingerprint images for re-offender recognition. With the increasing of the numbers of the data, the size of these databases are too big to handle sometimes, so ideas need to be found to reduce the storage size.

Fingerprint images have their own unique characteristics. These images are relatively simple, usually consisting of alternating ridges and valleys of roughly the same width. The features such as ridge tips and branch points must be well preserved during the compression process, otherwise these key features cannot be recovered after decompression. Therefore, algorithms that preserve these characteristics should be used for compression of fingerprint images.

The Wavelet Transformation has variable-sized processing regions. It can divide images into different frequency components, and analyze them individually with different solutions. This feature of the wavelet transformation perfectly matches the characteristics of fingerprints, as it can be used to reserve the relevant information of fingerprints, such as ridge tips and branch points, and ignore those less important information, such as white background and high frequency parts. By doing this, data could be better represented using wavelets. Thus, this technique will be implemented on the fingerprint images in this report.

2 Transformation

The wavelet transformation process is determined by various high- and lowpass filters. The wavelet transformation used in this project will be the Wavelet/Scalar Quantization (WSQ). The WSQ standard divides the original image into 64 subbands[2], as seen on fig. 1.

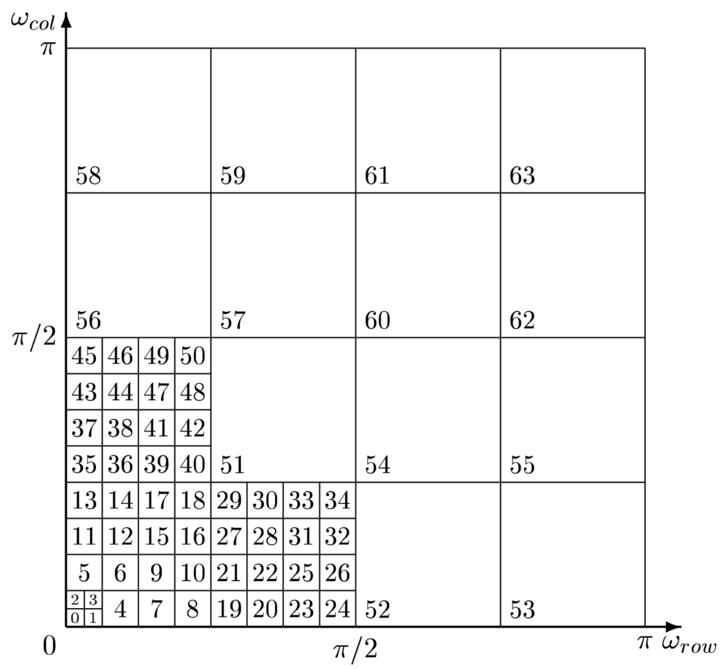

Figure 1: Frequency Subbands in WSQ[2]

The specific high- and lowpass filters used in the WSQ standard are known as the Biorthogonal Wavelet Family b4-4. This set of filters are defined given in [1], and can be seen in table 1. For the filtering, symmetric half and whole point extensions are used on the signal, depending on the size of the input signal.

Tap	Value
$h_0(0)$	0.8527
$h_0(\pm 1)$	0.3774
$h_0(\pm 2)$	-0.1106
$h_0(\pm 3)$	-0.0238
$h_0(\pm 4)$	0.0378

Table 1: Lowpass Wavelet Filters

3 Quantization

In the transformation part, the coefficient matrix has been divided into 64 subbands. This time, Wavelet Scalar Quantization (WSQ) quantization factor is going to used for fingerprint images. This technique is a lossy wavelet compression, and was developed by the FBI in 90s for them to store more fingerprint data. Unlike the quantization method that has been done in the DCT exercise, which has a fixed quantization step, WSQ quantization step will be determined by the absolute value of the coefficient in each subband. The higher the coefficient in that subband, the higher contribution it has for reconstructing the image. So, it is needed the establish a quantization strategy for each subband, which has different coefficient. A more precised quantization is required for high-coefficient subbands, and vise versa.

$$P_k^{(m,n)} = \begin{cases} \left[\dfrac{a_k^{(m,n)} - Z_{k/2}}{Q_k} \right] + 1, & \mathrm{a}_k^{(m,n)} > Z_{k/2} \\ 0 & -Z_{k/2} \le a_k(m,n) \le Z_{k/2} \\ \left[\dfrac{a_k^{(m,n)} + Z_{k/2}}{Q_k} \right] + 1, & \mathrm{a}_k^{(m,n)} < -Z_{k/2} \end{cases}$$

Figure 2: The Calculation of Quantization index

$$'\hat{a}' = \begin{cases} (P_k^{(m,n)} - C)Q_k + Z_{k/2,} & \mathrm{P}_\mathrm{k}^{(\mathrm{m,n})} > 0 \\ 0 & \mathrm{P}_\mathrm{k}^{(\mathrm{m,n})} = 0 \\ (P_k^{(m,n)} + C)Q_k - Z_{k/2,} & \mathrm{P}_\mathrm{k}^{(\mathrm{m,n})} < 0 \end{cases}$$

Figure 3: Transform coefficients formula in inverse WSQ

The formulas above are going to be used to calculate the quantized value of transform coefficient. Firstly, the encoder maps the values of transform coefficient 'a' to quantization index 'p'. The value of 'p' indicates which quantization bin 'a' lies. Secondly, at the receiver side, the received 'p' values will be used to calculate the values of 'a-hat', which are called the quantized wavelet coefficients.

4 Entropy Coding

After the quantization, the symbols are mapped to a series of symbols, which are then encoded using Huffman. Symbols 1 through 100 are used for transmitting 0 run-lengths. Run lengths larger than 100 can be encoded using symbol 105 or 106, depending on the length of the 0 run-length.Symbol 107 through 254 are used for transmitting actual index values, between -73 and 74. Symbol 101 through 104 can be used to encode values larger or smaller than this. An overview of this system can be seen on table 2.

Symbol	**Value**
1	zero run-length 1
2	zero run-length 2
3	zero run-length 3
⋮	⋱
100	zero run-length 100
101	escape for positive 8 bit value
102	escape for negative 8 bit value
103	escape for positive 16 bit value
104	escape for negative 16 bit value
105	escape for zero run, length of 8 bits
106	escape for zero run, length of 16 bits
107	index value -73
108	index value -72
109	index value -71
⋮	⋱
180	Not used
⋮	⋱
253	index value 73
254	index value 74

Table 2: Huffman Input Symbols[2]

The Huffman tables are dependant on the image, and are transmitted with the rest of the data. All subbands are coded using the same Huffman table, and the occurrence of each symbol in every subband must be counted to make the table. Transmission of the Huffman table is done by transmitting the array of code word lengths and a corresponding list of symbols[2].

This is counter to the original specification, that broke the image into anywhere from 3 to 8 blocks. This was to allow for gradual transmission, but this seems unnecessary with modern data-rates.

References

[1] J.N. Bradley and C.M. Brislawn. "Compression of fingerprint data using the wavelet vector quantization image compression algorithm. 1992 progress report". In: *Office of Scientific and Technical Information* (Apr. 1992). DOI: 10.2172/10114182. URL: https://www.osti.gov/biblio/10114182-compression-fingerprint-data-using-wavelet-vector-quantization-image-compression-algorithm-progress-report.

[2] Jonathan N. Bradley, Christopher M. Brislawn, and Thomas Hopper. "FBI wavelet/scalar quantization standard for gray-scale fingerprint image compression". In: *SPIE Proceedings* (1993). DOI: 10.1117/12.150973.

A Power spectral density of Fingerprint data

Most of the information found in fingerprint images are found in the low-frequency area [1]. The Power spectral density of the low frequency quadrant of the subband is shown on fig. 4

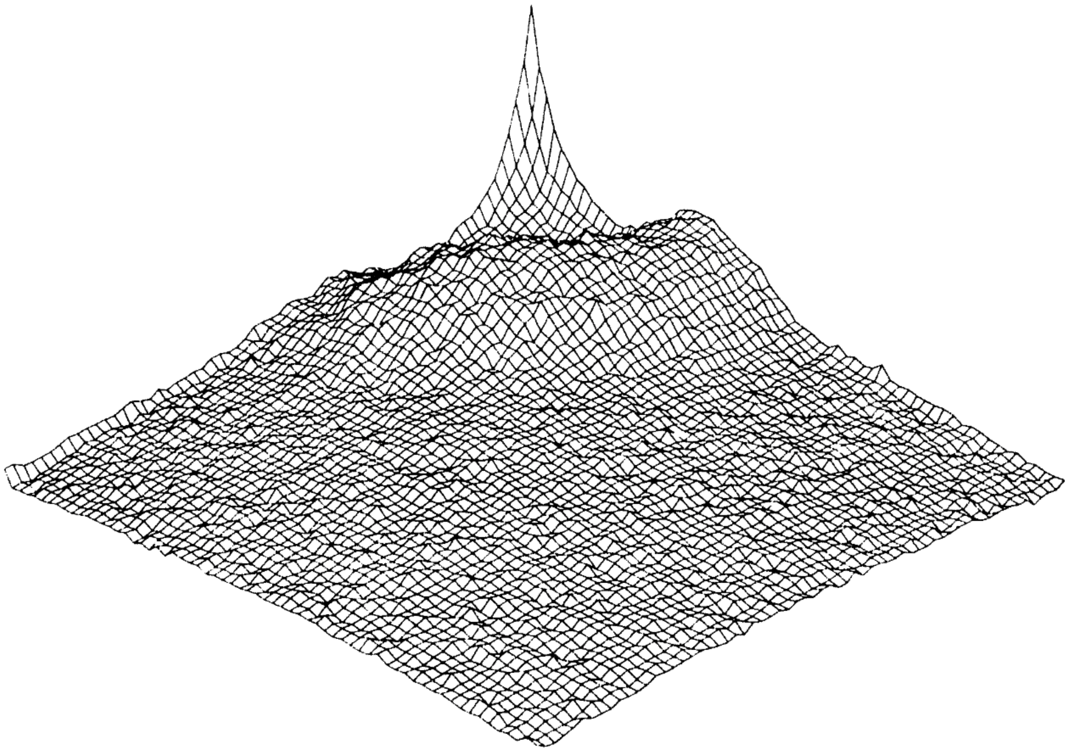

Figure 4: Two-Dimensional PSD Estimate of Fingerprint Data. Graph taken from [1]