Roger Piqueras Jover (39403203)
(w. Nadia Ahmed)

EECS 209A
Rendering Techniques for Biomedical Imaging

Final Project – Wavelet-based fabric texture characterization

1. Introduction

Wavelet decomposition techniques are procedures used to divide a given function into different frequency components and study each component with a resolution that matches its scale. Similar to a Fourier transform that represents a given signal based on its frequential components, a wavelet transform is the representation of a function by wavelets.

When working with Fourier transform-based techniques, a function is divided into its multiple frequential components, which are calculated as follows:

$$f(x) = a_0 + \sum_{k=1}^{\infty}\left(a_k \cdot \cos(kx) + b_k \cdot \sin(kx)\right)$$

Coefficients → $$a_0 = \frac{1}{2\pi}\int_0^{2\pi} f(x)dx$$

$$a_k = \frac{1}{\pi}\int_0^{2\pi} f(x)\cdot\cos(kx)dx \qquad b_k = \frac{1}{\pi}\int_0^{2\pi} f(x)\cdot\sin(kx)dx$$

On the other hand, the wavelets are scaled and translated copies of a finite-length or fast-decaying oscillating waveform. Wavelet transforms have advantages over traditional Fourier transforms for representing functions that have discontinuities and sharp peaks, such as square pulse shaped signals, which are commonly used to represent image signals, being each pixel represented by its value multiplied by a square pulse.

Representing such kinds of functions (e.g. images) by a Fourier decomposition would require an infinite number of coefficients. Therefore, wavelet decomposition-based techniques are appropriate for different kinds of image processing because they use this already mentioned different set of basis functions, the wavelets. These basis functions are orthogonal, have finite support and are box shaped (Figure 1).

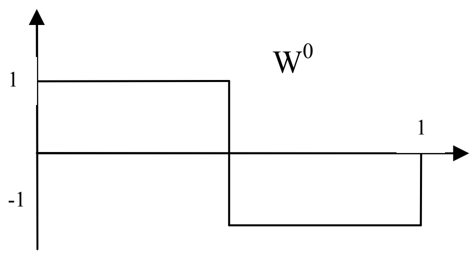

Figure 1: Example of a Wavelet

Another advantage of wavelet decomposition with respect of Fourier analysis is that the spatial information is preserved. The main difference is that wavelets are localized in both time and frequency whereas the standard Fourier transform is only localized in frequency. The Short-time Fourier transform (STFT) is also time and frequency localized but there are issues with the frequency time resolution and wavelets often give a better signal representation using multiresolution analysis.

1.1. Related work

As described in [1], wavelet transforms are now being adopted for a vast number of applications, often replacing the conventional Fourier transform. Many areas of physics have seen this paradigm shift, including molecular dynamics, ab initio calculations, astrophysics, density-matrix localisation, seismic geophysics, optics, turbulence and quantum mechanics.

Dealing with image processing, many wavelet-based works and applications are found among the literature. One use of wavelets is in data compression. Like some other transforms, wavelet transforms can be used to transform data, then encode the transformed data, resulting in effective compression. As an example, JPEG 2000 is an image compression technique based on wavelet decomposition. Other applications such as signal filtering are possible. Adaptive image filtering techniques are used to distinguish image features from noise and eliminate it as desired considering the characteristics of the noise. For example, usually high-frequency noise is more distracting than low-frequency noise, therefore a frequency specific solution is needed. Wavelet-based techniques are a good solution for band-pass filtering.

In [2], an image processing algorithm is presented that gathers these two already mentioned applications. The authors present a system that, by means of wavelet decomposition, allows image de-noising and compression.

2. Wavelet-based fabric texture characterization

This project's aim is to develop an algorithm that is able to analyse and distinguish different geometric patterns and textures for fabric. Basically, the different textures that will be analysed are the ones shown in Figure 2, which are vertical stripes, horizontal stripes and check board patterns.

		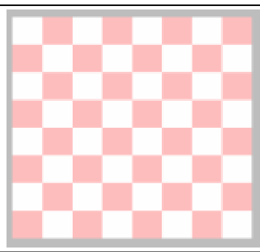
Vertical stripes	Horizontal stripes	Checkboard pattern

Figure 2: Texture patterns analyzed by the algorithm

The algorithm analyses the frequency components of the fabric pattern as well as the kind of pattern the fabric presents. Both results are acquired by a wavelet decomposition-based procedure.

2.1. Algorithm's theoretical basis

In order to detect the fabric's pattern and determine its frequency, the algorithm proceeds on a multiple level wavelet decomposition of the image (Figure 3). This decomposition is realised many times, and each time one frequency component is eliminated.

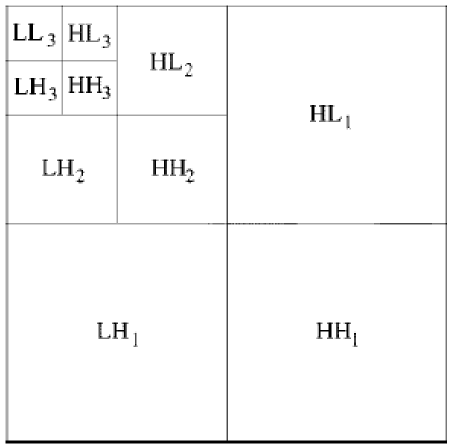

Figure 3: Two level Wavelet decomposition

When dealing with vertical and horizontal stripes, or a check board pattern, the behaviour of the wavelet decomposition is as follows. As already mentioned, on each level of the decomposition, one frequency component is eliminated. If the image does not contain this specific frequency component, the resulting HL, LH and HH regions of the decomposition have a value close to zero. On the contrary, if the image does contain this specific frequency, the value of one of this regions will be high, which indicates that the image contains that frequency. Whether the high value is located in the HL, LH, or HH region, determines the axis in which the frequency component is located.

As the decomposition is done in multiple levels, every possible frequency (from higher to lower frequencies) is scanned. This procedure allows the frequency decomposition of a given image. As an example, Figures 4 to 9 depict this analysis for both a vertical line pattern and checkboard pattern for different frequencies.

10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2

Initial image

10	10	2	2	0	0	0	0
10	10	2	2	0	0	0	0
10	10	2	2	0	0	0	0
10	10	2	2	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Freq_x=1

10	2	0	0
10	2	0	0
0	0	0	0
0	0	0	0

Freq_x=2

6	4
0	0

Freq_x=3

Figure 4: Multilevel wavelet decomposition of a vertical stripes pattern (freq_x=3)

10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2

Initial image

10	2	10	2	0	0	0	0
10	2	10	2	0	0	0	0
10	2	10	2	0	0	0	0
10	2	10	2	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Freq_x=1

6	6	4	4
6	6	4	4
0	0	0	0
0	0	0	0

Freq_x=2

Figure 5: Multiple level wavelet decomposition of a vertical stripes pattern (freq_x=2)

10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2
10	2	10	2	10	2	10	2

Initial image

6	6	6	6	4	4	4	4
6	6	6	6	4	4	4	4
6	6	6	6	4	4	4	4
6	6	6	6	4	4	4	4
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Freq_x=1

Figure 6: Multiple level wavelet decomposition of a vertical stripes pattern (freq_x=1)

10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
10	10	10	10	2	2	2	2
2	2	2	2	10	10	10	10
2	2	2	2	10	10	10	10
2	2	2	2	10	10	10	10
2	2	2	2	10	10	10	10

Initial image

10	10	2	2	0	0	0	0
10	10	2	2	0	0	0	0
2	2	10	10	0	0	0	0
2	2	10	10	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Freq_xy=1

10	2	0	0
2	10	0	0
0	0	0	0
0	0	0	0

Freq_xy=2

6	0
0	4

Freq_xy=3

Figure 7: Multiple level wavelet decomposition of a check board pattern (freq_xy=3)

10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
2	2	10	10	2	2	10	10
2	2	10	10	2	2	10	10
10	10	2	2	10	10	2	2
10	10	2	2	10	10	2	2
2	2	10	10	2	2	10	10
2	2	10	10	2	2	10	10

Initial image

10	2	10	2	0	0	0	0
2	10	2	10	0	0	0	0
10	2	10	2	0	0	0	0
2	10	2	10	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Freq_x=1

6	6	0	0
6	6	0	0
0	0	4	4
0	0	4	4

Freq_x=2

Figure 8: Multiple level wavelet decomposition of a check board pattern (freq_xy=2)

10	2	10	2	10	2	10	2
2	10	2	10	2	10	2	10
10	2	10	2	10	2	10	2
2	10	2	10	2	10	2	10
10	2	10	2	10	2	10	2
2	10	2	10	2	10	2	10
10	2	10	2	10	2	10	2
2	10	2	10	2	10	2	10

Initial image

6	6	6	6	0	0	0	0
6	6	6	6	0	0	0	0
6	6	6	6	0	0	0	0
6	6	6	6	0	0	0	0
0	0	0	0	4	4	4	4
0	0	0	0	4	4	4	4
0	0	0	0	4	4	4	4
0	0	0	0	4	4	4	4

Freq_x=1

Figure 9: Multiple level wavelet decomposition of a check board pattern (freq_xy=1)

Therefore, by means of a multilevel wavelet decomposition, the frequency of a fabric pattern can be determined. Furthermore, the kind of pattern can be determined depending on where the frequency component is located. For example, as shown above, the algorithm determines a check board pattern when a frequency component is located on the HH region of the wavelet decomposition.

2.2. Algorithmic structure

The algorith structure is defined as follows. First of all the user selected image is loaded into a temporal buffer. Input images must be Portable Gray Map (.pgm) formatted, square and with each size being equal of a power of two. Then, by means of determining the image size, a maximum number of iterations is determined as follows:

$$\text{Maximum number of iterations} = \log_2(\text{size\_x}) = \log_2(\text{size\_y})$$

For example, for a 512x512 pixels image, the maximum number of iterations is 9.

Then, the algorithm proceeds to a multilevel wavelet decomposition of the image. The image is analysed and, if no frequencial component is detected, the next level of decomposition computes the wavelet decomposition of the last LL area. Following this procedure, the image that is analysed is 4 times smaller (2 times smaller in each dimension) at every iteration.

When the wavelet-based analyses has been done for every possible iteration, the results are shown according to the frequencies and patterns detected. This detection is simply done by averaging the values of each HH, LH, HL regions and comparing these averaged values with a predefined threshold that sets the sensitivity of the algorthm’s detection.

This whole procedure is depicted by Figure 10 and the core of the algorithm’s core code is shown in Figure 11.

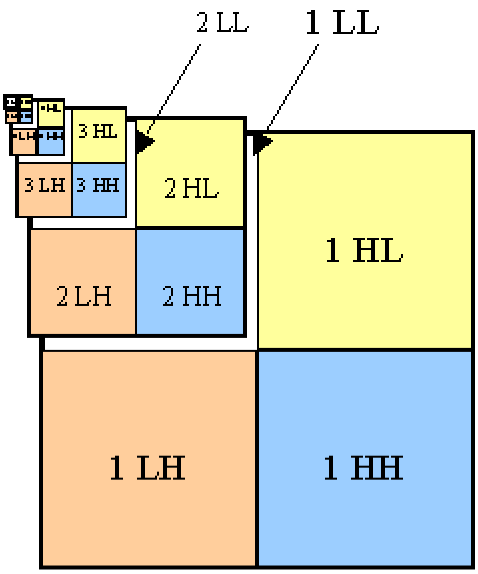

Figure 10: Multilevel wavelet decomposition

```
printf("Starting detection...\n");

i=0;
while(size_x/pow(2,i)>1){
      printf("Iteration number %d, starting wavelet
      decomposition...\n",i);

      wavelet_decomposition(i);

      printf("Wavelet decomposition for iteration %d done, checking
      for texture...\n",i);

      if(!x_y_done){
            if(check_HH(i)==1){
                  x_y_done=1;
                  f_x_y=i;
                  break;
            }
      }
      if(!x_done){
            if(check_HL(i)==1){
                  x_done=1;
                  f_x=i+1;
                  break;
            }
      }
      if(!y_done){
            if(check_LH(i)==1){
                  y_done=1;
                  f_y=i+1;
                  break;
            }
      }
      i++;
}
```

```
if(f_x==0 && f_y==0 && f_x_y==0){
            printf("Constant image.\n");
            printf("Frequency x: %d; Frequency y:%d.\n",f_x,f_y);
      }
      else if(f_y==0 && f_x_y==0){
            printf("Vertical lines pattern.\n");
            printf("Frequency x: %d.\n",f_x);
      }else if(f_x==0 && f_x_y==0){
            printf("Horizontal lines pattern.\n");
            printf("Frequency y: %d.\n",f_y);
      }else if(f_x_y!=0){
            printf("Checkboard pattern.\n");
            printf("Frequency : %d.\n",f_x_y);
      }
}
```

Figure 11: Algorithms core code

3. Results

The results are obtained in two different stages. First of all, a set of testing images is generated. After testing the algorithm with these testing images, the detection technique is applied to actual fabric pattern images.

3.1. Testing images

By means of an image generating custom algorithm, a set of test images is generated. Basically, these images are vertical stripes, horizontal stripes and check board patterns of different frequencies.

This kind of images allow us to test the algorithm in the multiple wavelet decomposition stage step by step. For example, Figure 12 shows two of these test images. In this case, they are a vertical stripes and horizontal stripes pattern, both with the highest frequency possible, which is with a change on the pixel value every single pixel. Applying this images to the algorithm core will allow a test for the first iteration of the multilevel wavelet-based analysis.

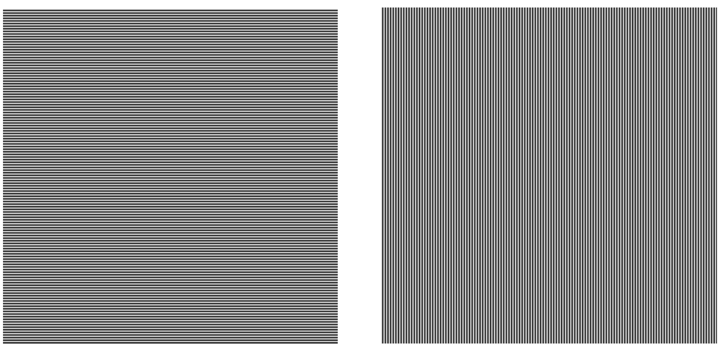

Figure 12: Test images with frequency 1

By using these test images, the algorithm is tested and ready to be applied to actual fabric patterns. For these next analysis, the threshold for detection will need to be adjusted in order to detect smoother variations, since the test images contain just two levels of intensity (0:black, 255:white).

3.2. Fabric texture detection

Finally, actual sample images from fabric are obtained from the Internet. These images are transformed to grey scale and resized to be square and with size equal to a power of two. After this process, the algorithm is tested using these images.

In this case, the results achieved by the algorithm are less optimal and they tend to present incorrect detections or even lack of detection in some cases. This is mainly because of the characteristics of this kind of images. For example, the vertical lines image on Figure 2 presents a clear vertical stripes pattern. However, the colours of each line don't present abrupt changes of intensity from one stripe to the other one, and this smoothness of the transitions is increased when the image is transformed to grey scale. This can be observed in Figure 13.

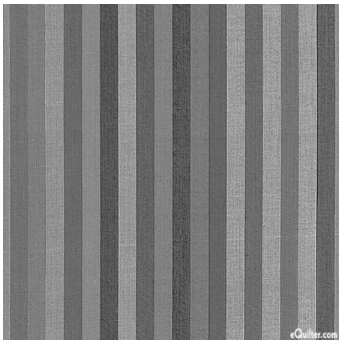

Figure 13: Vertical stripes pattern transformed to gray scale

Also, the algorithm has trouble to analyse fabric patterns whose stripes have not the same width.

4. Conclusions

A wavelet-based algorithm to analyse and detect patterns in fabric samples have been presented. By means of a multi level wavelet decomposition, three different patterns (vertical stripes, horizontal stripes and check board pattern) are detected and through the same analysis, the frequency of each pattern is calculated.

Using a custom image generator algorithm, a set of testing images is created. These test images are used to test the algorithm in a sequential way, by selecting the number of iterations desired, which are related to the width of the stripes/squares of each pattern.

By using these images, the algorithm performs good results and detects the three possible patterns. Furthermore, it is able to calculate the frequency of each pattern. However, when applying the algorithm to actual fabric samples, the results are not that good. After transforming the fabric colour images to grey scale, in some cases the transitions between the stripes/squares are not strong enough to detect the pattern. Furthermore, a typical trend in fabric samples are stripes with different width, which leads to multiple frequency component, which the algorithm can't detect.

5. References

[1] WikiPedia (http://en.wikipedia.org/wiki/Wavelet)

[2] S. GRACE CHANG, BIN YU, MARTIN VETTERLI. “Adaptive Wavelet Thresholding for Image Denoising and Compression”. IEEE Transactions on Image Processing, vol. 9, no. 9, September 2000

[3] MALLET, Y.[YVETTE], COOMANS, D., KAUTSKY, J., DE VEL, O., “Classification Using Adaptive Wavelets for Feature-Extraction”, IEEE Transactions on Pattern Analysis and Machine Intelligence, Volume: 19 Issue: 10, October 1997

[4] MAGLI, E.; OLMO, G., "Integrated compression and linear feature detection in the wavelet domain", Proceedings International Conference on Image Processing, 2000.Volume 3, Issue , 2000 Page(s):889 - 892 vol.3

[5] Images from Google Images