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A mobile image enhancement technology for visually impaired

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A MOBILE IMAGE ENHANCEMENT TECHNOLOGY FOR VISUALLY IMPAIRED

By

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A THESIS

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Abstract

In this thesis, an image enhancement application is developed for low-vision patients when they use iPhones to see images/watch videos. The thesis has two contributions. The first contribution is the new image enhancement algorithm which combines human vision features. The new image enhancement algorithm is modified from a wavelet transform based image enhancement algorithm developed by Dr. Jinshan Tang. Different from the original algorithm, the new image enhancement algorithm combines human visual feature into the algorithm and thus can make the new algorithm more effective. Experimental simulation results show that the proposed algorithm has a better visual results than the algorithm without combining visual features. The second contribution of this thesis is the development of a mobile image enhancement application. In this application, users with low-vision can see clearer images on an iPhone which is installed with the application I have developed.

Index Terms—Image enhancement, wavelet transform, human visual features, blurred image, iPhone, mobile application, simulations

Chapter 1 Introduction

1.1 Image enhancement for low-vision patients

Based on the statistics of the World Health Organization (WHO), the population of low-vision patients has reached around one hundred and sixty-five millions. Meanwhile, that population is still rising by twenty one millions per year [1]. The prevalence rates of low-vision have been ranging from 2.7% to 5.8% in recent years [2].

Low-vision is a kind of visual impairment that affects people's daily lives, but parts of useful vision still remain. People suffering from low-vision cannot reach ordinary levels even wearing normal glasses or normal contact lenses because of loss of visual acuity and field of vision. Low-vision patients have difficulties in reading papers, recognizing faces, using computers and mobile phones, watching television, etc.

Lots of research has been done to aid patients with low-vision. One of the important research areas is image enhancement technology. Image enhancement can be used to help low-vision patients to get high-quality images with digital devices [4,5,6]. A lot of work has been done in this area. For example, in [7], a systematic contrast-enhancement method has been presented to improve the content visibility for low vision patients who have the symptoms of loss of fine details and lack of contrast [7]. In [8], a strong edge enhancement method was developed to make the images to have a better visual effect for low-vision patients. Experiments show that the developed method could make the visually impaired succeed in recognizing most of the objects in an image [8]. Low-vision people have a lower ability seeing public signals under a poor environment. In order to target these situations, some applications such as enlarging the targets on visually impaired mobile displays [9] were developed. Currently the images obtained from different resources are color

images and thus how to enhance color images for low-vision patients is another research topic. In [10], image enhancement technology for color images were investigated. Experiments with a pair of simulation glasses were performed and experimental results show that the proposed enhancement algorithm for color images is effective. In [11], an image enhancement algorithm based on the wavelet transform method was proposed. The algorithm can enhance the images by manipulating the decomposition detail coefficients. Experiments were performed using both a normal-vision person and a visually impaired patient by give their opinions on the enhanced image they saw obtained by the new algorithm. The experimental results show that the visually impaired patient preferred the enhanced version over the original images. In [12], image enhancement technology was used to aid the visually impaired in face recognition. By establishing the pre-emphasis model and contrast sensitivity function in [12], low-vision patients could compare the original images with the enhanced images. Experimental results show that image enhancement can improve face recognition rates. Besides the paper mentioned above, there are many other papers that deal with image enhancement for low-vision patients.

With the development of science and technology, mobile devices such as the iPad or iPhone have become popular in our daily lives and thus also provide convenient tools for low-vision patients. Low-vision patients can use mobile device to read text, watch video/see images, find the routes, etc. However, similar to other electronic devices, the information needs to be through special processing before it can reach low-vision patients. For example, the texts need to be magnified before the low-vision patients can read, the images/videos need to be enhanced before the low vision patients can see/watch [13]. There are many papers dealing with text magnification but not too much research on image enhancement for mobile devices. In this thesis, we will focus on the image enhancement techniques for mobile devices.

1.2 Some image enhancement methods

There are two main methods in digital image enhancement: spatial domain method and frequency domain method. Spatial domain method mainly processes the pixel in the image on the basis of gray mapping transformation. Frequency domain method is based on convolution theorem. In general, frequency domain method uses frequency transform such as Fourier transform method to achieve image enhancement. The process of image enhancement through frequency domain method can be represented as figure 1.

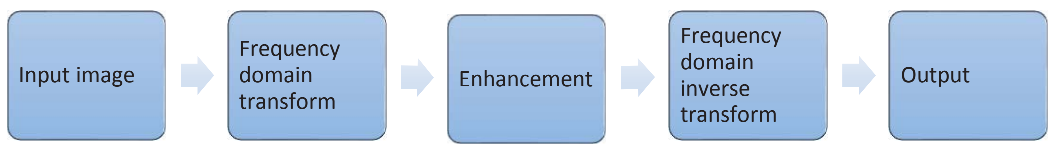


Figure 1. Frequency domain method

1.2.1. Gamma correction

Gamma correction is a spatial domain technique. As is well known, the quality of the image could be influenced by many factors, such as the weather, the precision of the camera, optical system, etc. The images captured might be lighter or darker than expected. For this kind of quality degradation, gray level stretching can be used to achieve the aim. By redistributing the original image's gray levels, an image could have better quality.

1.2.2. Histogram equalization

The principle of histogram equalization is to distribute the gray-scale equalization of the original image uniformly from a typical gray zone to the entire gray range. Histogram equalization is a nonlinear stretching of the image. It re-allocates image pixel values and makes the amount of the pixels in every certain gray range as similar as possible. Histogram equalization changes the histogram distribution of a given image to a uniform histogram distribution.

Histogram equalization sometimes would reduce gray-scale so that some details would disappear after converting.

1.2.3. Discrete Cosine Transform (DCT)

Besides image enhancement in the spatial domain, there are also many image enhancement techniques performed in frequency domain, such as the image enhancement based on Fourier transform, discrete cosine transform (DCT), and so on. The advantage of image enhancement in frequency domain lies in that image enhancement can be performed by selecting the frequencies. This is very important for low-vision patients because some patients cannot see some special frequencies.

One important image enhancement in the frequency domain is DCT-based image enhancement techniques. Besides the advantage mentioned above, DCT-based image enhancement techniques can save time when the image to be enhanced in JPEG format because we can perform the enhancement in the decoding stage.

The DCT based image enhancement for a JPEG image in the decoding stage can be described by Figure 2 [14].

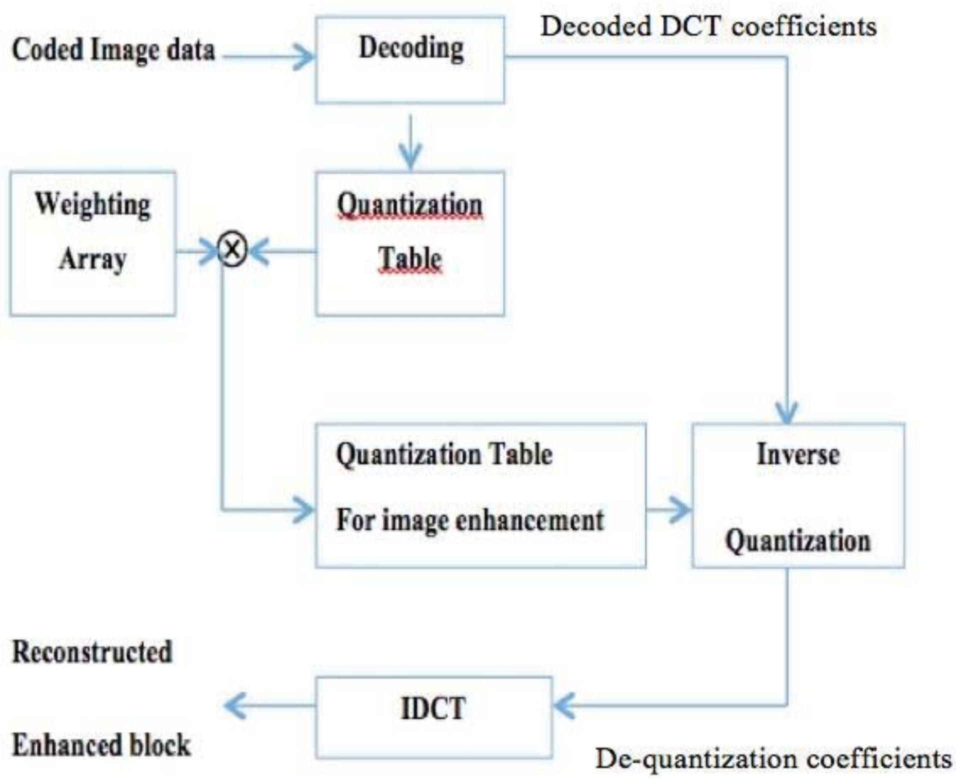


Figure 2. Image enhancement in JPEG domain based on the method described in [14]

1.2.4. Image enhancement with wavelet transform

Besides image enhancement techniques in spatial and frequency domains, another image enhancement technique is performed in a time (spatial)-frequency domain.

Wavelet transform-based image enhancement is one of these techniques. In recent decades, wavelet transform has become an important topic in image processing areas and has found wide applications in different areas. It has been applied to image compression, noise reduction, image enhancement and so on.

In wavelet transform based image enhancement [15], the image is first transformed into wavelet domain. The image enhancement can be achieved by the modification of the wavelet coefficients. Different techniques to modify the wavelet coefficient techniques have been proposed. One of the techniques is the technology developed by Dr. Jinshan Tang in [16]. The basic idea of Tang's algorithm is to define a multi-contrast measure in the wavelet domain. The enhancement can be achieved by directly modifying the contrast of the image. The proposed method has been found very effective for mammogram enhancement.

The advantage of wavelet transform-based image enhancement lies in the decomposition of the content of the original image into multi-scale frequencies which match the human visual system and thus the enhancement can be performed using human visual features. Another benefit lies in that the enhancement can save time when the images to be enhanced are in the JPEG2000 format.

1.3 Statement of Problem

The aim of this thesis is to investigate new image enhancement algorithms and their application in mobile device (iPhone). The proposed algorithm is based on wavelet transform and visual weighting. In the proposed algorithm, the key point is the contrast enhancement in wavelet domain through contrast sensitive function masking. Experiments through changing the contrast manipulation factors were performed to

get the best enhanced images. In the experiments, subject tests were used to test the performance of the algorithms by comparing images enhanced by the proposed algorithm and by Tang's algorithm. Besides, a mobile application for visually impaired was developed. The application could run on IOS devices such as iPhone, iPad. Users with an iPhone installed with the proposed application can use the iPhone as a test tool to get the enhanced version of an image.

The rest of the thesis is organized as follows. In Chapter 2, some basic wavelet transform knowledge and Tang's algorithm are introduced. Then, I investigate a visual weighting image enhancement algorithm based on human visual system. In Chapter 3, IOS system is introduced. On the IOS platform, Tang's algorithm and visual weighting image enhancement algorithm are implemented. Chapter 4 describes the experiments which are used to compare the two algorithms.

Chapter 2 A visual weighting image enhancement algorithm

As is well known, wavelet transform based image enhancement has many advantages. However, Tang's algorithm didn't combine human visual feature. Human visual feature plays an important role when the image is enhanced for human being to see/watch, thus how to combine human visual feature into image enhancement algorithm will get better visual effects. In this chapter, a new image enhancement algorithm based on wavelet transform combining human visual features is proposed.

2.1. 2-D Discrete Wavelet Transform

Wavelet transform is a kind of a time-scale analysis method of signal, which has the characteristics of multi-resolution analysis [17]. It is a time-frequency analysis method. After wavelet transform, a signal is decomposed into multi-scale subbands. At a low frequency portion, it has a higher frequency resolution and a lower time resolution. In contrast, at a high frequency portion, it has a higher time resolution and a lower frequency resolution [17].

The wavelet transform used in this paper is 2-D Discrete wavelet transform. Let $A_0(m,n)$ be a 2-D image, $\{h_n\}$, $\{g_n\}$ be wavelet analysis filters, and $\{\hat{h}_n\}$, $\{\hat{g}_n\}$ are wavelet synthesis filters. Then the K^{th} level wavelet transform $\{A_N(m,n), D_N^1(m,n), D_N^2(m,n), D_N^3(m,n)\}_{N=1}^{K}$ of the original image $A_0(m,n)$ can be described as [18]:

$$A_N(m,n) = \sum_{x,y \in Z} h(x)h(y)A_{N-1}(2m-x, 2n-y) \quad (1)$$

$$D_N^1(m,n) = \sum_{x,y \in Z} h(x)g(y)A_{N-1}(2m-x, 2n-y) \quad (2)$$

$$D_N^2(m,n) = \sum_{x,y \in Z} g(x)h(y)A_{N-1}(2m-x, 2n-y) \quad (3)$$

$$D_N^3(m,n) = \sum_{x,y \in Z} g(x)g(y)A_{N-1}(2m-x, 2n-y) \quad (4)$$

where $A_N(m,n)$ represents the low-frequency content of $A_{N-1}(m,n)$. $D_N^1(m,n)$ represents the horizontal low-frequency, and vertical high frequency content of $A_{N-1}(m,n)$, $D_N^2(m,n)$ represents the vertical low frequency and horizontal high frequency content of the image $A_{N-1}(m,n)$ and $D_N^3(m,n)$ represents the vertical high frequency and horizontal high frequency content of $A_{N-1}(m,n)$ [16].

Figure 3 shows 2-level wavelet transform of an image.

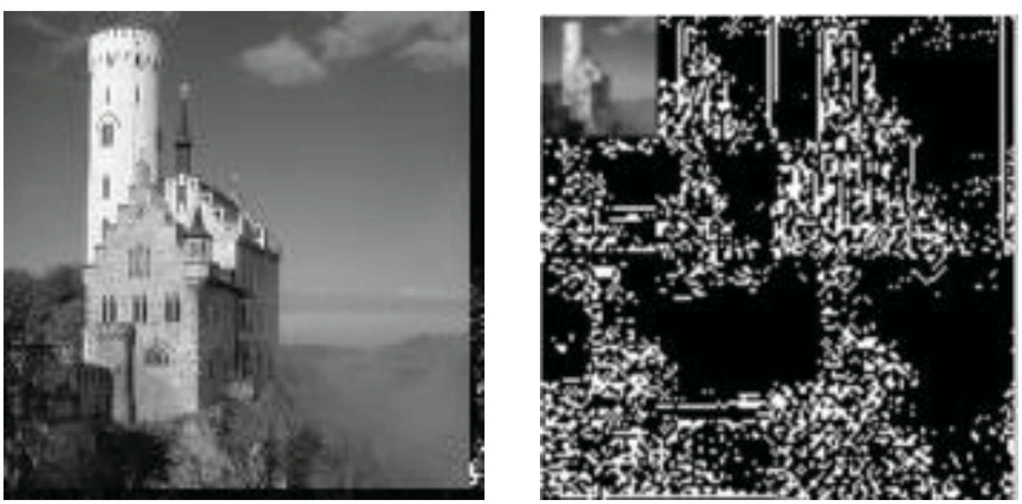


Figure 3. (a). The original image; (b).Image with 2-level wavelet transform created by me in MATLAB platform and all rights are reserved.

The reconstruction algorithm of the decomposition in (1)~(4) is[18]:

$$A_{N-1}(m,n) = 4 \times [\sum_{x,y\in Z} \hat{h}(x)\hat{h}(y)A_N\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z} \hat{h}(x)\hat{g}(y)D_N^1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z} \hat{g}(x)\hat{h}(y)D_N^2\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z} \hat{g}(x)\hat{g}(y)D_N^3\left(\frac{m-x}{2},\frac{n-y}{2}\right)]$$

2.2. Direct contrast enhancement in the wavelet domain-Tang's algorithm

Image enhancement in the wavelet domain can be performed by the modification of the wavelet coefficients. There are several ways to modify the wavelet coefficients. One way is to modify coefficients by modifying the contrast of the images. In order to modify the contrast of the image, it needs to develop a contrast measurement to measure the contrast of the image. There have developed many contrast measures in the past [19][23]. However, not all contrast measurement could measure the contrast in complex images. For example, Michelson contrast measure and Weber contrast measure [16] can be only applied to images with simple patterns. Several other contrast measures were developed specifically for complex images, such as the image enhancement method developed by Eli Peli [24], and the contrast measure developed by Sos Agaign[25], the contrast measure developed Jinshan Tang[23].

In wavelet transform-based image enhancement, Tang used a contrast measure similar to Peli's contrast measure but it is defined in the wavelet domain. The contrast measure Dr. Tang used is a multi-scale contrast measure defined in the wavelet domain. The multi-scale contrast measure can be defined as [16]:

$$\mathrm{c}_{\mathrm{N}}^{\mathrm{k}}(m,n) = \frac{\mathrm{D}_{\mathrm{N}}^{\mathrm{k}}(m,n)}{\mathrm{A}_{\mathrm{N}}(m,n)} \quad (\mathrm{k} = 1,2,3) \tag{6}$$

Equation (6) can be used to measure the vertical contrast, the horizontal contrast and the diagonal contrast [16], thus the contrast measure is better than Eli Peli's measure because it can be used for directional noise reduction and direction contrast enhancement [16].

Based on the contrast measure developed in (6), Dr. Tang developed an image enhancement algorithm in the wavelet domain. The image enhancement algorithm starts from the highest-level after wavelet decomposition. The original image $\mathrm{A}_0(m,n)$ is performed $K-level$ decomposition and the obtained components' subband would be [16]:

$$\{\mathrm{A}_{\mathrm{K}}(m,n), \mathrm{D}_{\mathrm{K}}^{1}(m,n), \mathrm{D}_{\mathrm{K}}^{2}(m,n), \mathrm{D}_{\mathrm{K}}^{3}(m,n) \ldots, \mathrm{A}_{1}(m,n), \mathrm{D}_{1}^{1}(m,n), \mathrm{D}_{1}^{2}(m,n), \mathrm{D}_{1}^{3}(m,n)\} \tag{7}$$

After the mutli-scale decomposition is obtained, we will modify the wavelet coefficients by the modification of the multi-scale contrast values. Let the multi-scale contrast of the original image be $\mathrm{c} = \left\{\mathrm{c}_{\mathrm{N}}^{\mathrm{k}}(m,n)\right\}$, the mutli-scale contrast of the reconstructed (enhanced) image be $\bar{\mathrm{c}} = \{\bar{\mathrm{c}}_{\mathrm{N}}^{\mathrm{k}}(m,n)\}$, then the relationship between the two multi-scale contrasts can be obtained by a linear relation, which can be described by

$$\bar{\mathrm{c}}_{\mathrm{N}}^{\mathrm{k}}(m,n) = \lambda_{\mathrm{N}}^{\mathrm{k}}(m,n)\mathrm{c}_{\mathrm{N}}^{\mathrm{k}}(m,n) \tag{8}$$

where $\lambda = \{\lambda_N^k(m,n)\}$ is called contrast manipulation factor[16]:

Based on equation (8), the image can be enhanced by iterative steps. Through the K^{th} subbands components $A_N(m,n), D_N^1(m,n), D_N^2(m,n), D_N^3(m,n)$ and equation (8), we can get:

$$\frac{\bar{D}_N^k(m,n)}{\bar{A}_N(m,n)} = \bar{c}_N^k(m,n) = \lambda_N^k(m,n) c_N^k(m,n) = \lambda_N^k(m,n) \frac{D_N^k(m,n)}{A_N(m,n)} \tag{9}$$

Let

$$\bar{A}_N(m,n) = A_N(m,n)$$

$$\bar{D}_N^1(m,n) = \lambda_N^1(m,n) D_N^1(m,n)$$

$$\bar{D}_N^2(m,n) = \lambda_N^2(m,n) D_N^2(m,n)$$

$$\bar{D}_N^3(m,n) = \lambda_N^3(m,n) D_N^3(m,n).$$

Then, the way to get $\bar{A}_{N-1}(m,n), \bar{D}_{N-1}^1(m,n), \bar{D}_{N-1}^2(m,n), \bar{D}_{N-1}^3(m,n)$ was similar to equation (9)

$$\frac{\bar{D}_{N-1}^k(m,n)}{\bar{A}_{N-1}(m,n)} = \bar{c}_{N-1}^k(m,n) = \lambda_{N-1}^k(m,n) c_{N-1}^k(m,n) = \lambda_{N-1}^k(m,n) \frac{D_{N-1}^k(m,n)}{A_{N-1}(m,n)} \tag{10}$$

Equation (10) could be changed to:

$$\bar{D}_{N-1}^k(m,n) = \lambda_{N-1}^k(m,n) \frac{D_{N-1}^k}{A_{N-1}} \bar{A}_N(m,n) \tag{11}$$

$\bar{A}_N(m,n)$ can be obtained by

$$\bar{A}_{N-1}(m,n) = 4 \times \left[\sum_{x,y \in Z} \hat{h}(x)\hat{h}(y)\bar{A}_N\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y \in Z} \hat{h}(x)\hat{g}(y)\bar{D}_N^1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y \in Z} \hat{g}(x)\hat{h}(y)\bar{D}_N^2\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y \in Z} \hat{g}(x)\hat{g}(y)\bar{D}_N^3\left(\frac{m-x}{2},\frac{n-y}{2}\right) \right] \quad (12)$$

Similarly, the other enhanced subband components could be obtained. After getting $\bar{A}_1(m,n), \bar{D}_1^1(m,n), \bar{D}_1^2(m,n), \bar{D}_1^3(m,n)$, the following formula could be used to obtain the enhanced image $\bar{A}_0(m,n)$:

$$\bar{A}_0(m,n) = 4 \times \left[\sum_{x,y \in Z} \hat{h}(x)\hat{h}(y)\bar{A}_1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y \in Z} \hat{h}(x)\hat{g}(y)\bar{D}_1^1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y \in Z} \hat{g}(x)\hat{h}(y)\bar{D}_1^2\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y \in Z} \hat{g}(x)\hat{g}(y)\bar{D}_1^3\left(\frac{m-x}{2},\frac{n-y}{2}\right) \right] \quad (13)$$

Figure 4 shows the image enhancement results using Tang's algorithm.

Figure 4. Implementation of Tang's algorithm created by me in MATLAB (all rights are reserved) with same λ.

2.3. The Proposed Algorithm

2.3.1. Human Visual System (HVS)

Human's eyes can be described as an optical system with nervous system regulation [26]. When people are observing images, in a spatial frequency domain, the human eye is a low-pass linear system [27]. Experiments have shown that human's eyes have logarithmic non-linear properties for luminance so that the eyes' vision can reach the luminance's dynamic range [28]. Therefore, human's eyes are not sensitive

of the gray-scale deviation in the area in which luminance is not very high. From signal analysis theory, for the human visual system, weighted summation on the signal is equivalent to passing a band-pass filter on a signal. That would make human's eyes produce a feeling of side-enhancement which is called Lateral inhibition effect [29]. Image edge information is an important part for human's vision. Human's eyes are much more sensitive of the edge's position change than edge's gray-scale deviation [30]. The masking effect of human vision is a kind of local effect. It is affected by illumination of the background, the complexity of texture and the frequency of signal. [31].

2.3.2. Contrast sensitivity function (CSF)

A lot of research on the human visual system has been done to develop mathematical models to describe the human's vision system [32]. In mathematical models, the contrast sensitive function (CSF) is used to describe human's sensitivity to spatial frequencies [32]. One of the CSF models for gray image is proposed by Mannos and Sakrison which can be described as follows [33][34]

$$h(f) = 2.6 \times (0.192 + 0.114f)e^{[-(0.114f)^{1.1}]} \tag{14}$$

where f is the spatial frequency, whose unit is cycles/degree. Considering the direction of spatial frequency and letting f_x and f_y be the spatial frequency in the horizontal and vertical directions respectively, the spatial frequency can be written as follows [35]

$$f = ({f_x}^2 + {f_y}^2)^{\frac{1}{2}} \tag{15}$$

From the equation (14) and equation (15), when $f_x = 0$, $f = f_y$, and when $f_y = 0$,

$f = f_x$. So that the function of normalized spatial frequency can be shown as Figure 5[35]

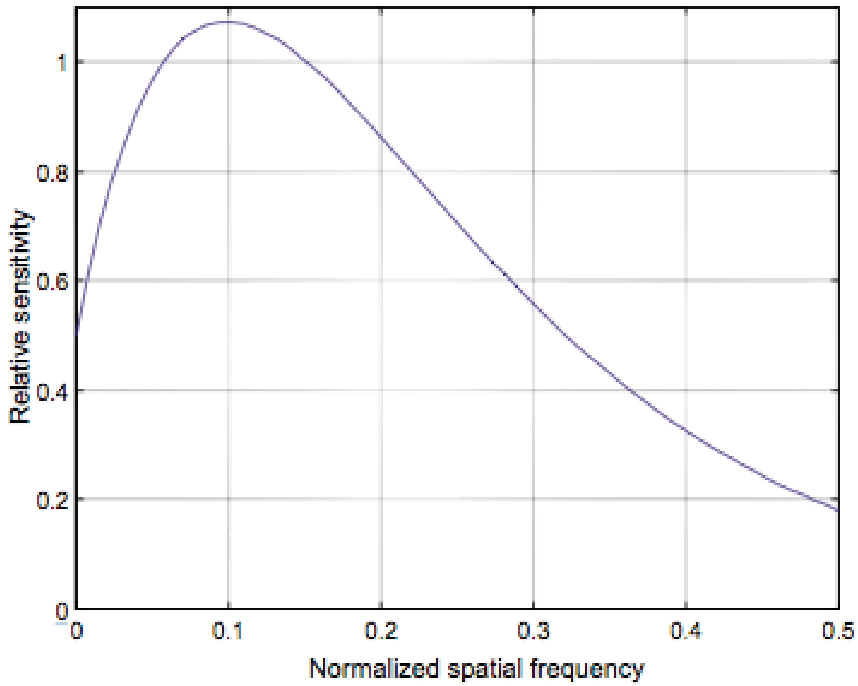


Figure 5. Normalized CSF Curve based on the method described in [35]

2.3.3. Band-average CSF Masking

To weight the wavelet coefficients relative to the perceptual importance, CSF masking was named and was applied to the compression system [35].

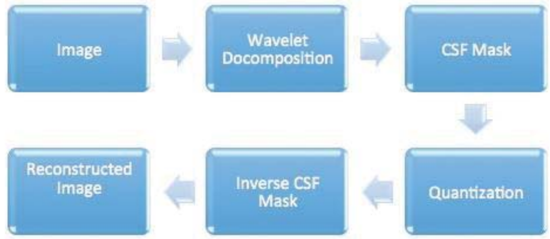


Figure 6. CSF masking diagram based on the method described in [35]

Figure 6 shows the subsequence of the compression system with the CSF mask applied. In [35], from the CSF curve in the normalized spatial frequency domain which is presented from equation (14), equation (15), and the diagram above, the six-CSF-weight mask was computed as the average of the CSF curve in its corresponding frequency band [35]. The six-weight, band-average CSF mask can be shown as Figure 7.

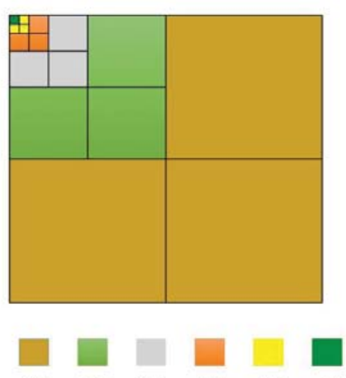


Figure 7. Six unique weights band-average CSF mask based on the method described in [35]

2.3.4. Weighting contrast manipulation factors

When processing the wavelet signal decomposition, multi-level decomposition would be done to get the low-frequency details and high-frequency details. In Tang's algorithm, different scales' content could be enhanced through its enhancement contrast manipulation factors, $\lambda_{N}^{k}(m,n)$. However, different details sometimes have different enhancement requirements in different scales. So that the single enhancement factor may not be the best way to get the best effective result of the image enhancement.

In the new algorithm, every detail's contrast manipulation factors were made independent through the research of CSF and six unique weights were obtained from a five-level wavelet decomposition image.

From Figure 8, each scale's weight is sorted by different colors. Each weight on every level's wavelet decomposition is marked, so that we can get the new contrast manipulation factors using these following equations

$$\nu_{N}^{k} = \frac{V_n}{\sum_{(n \epsilon Z)} V_n} \cdot \lambda' \tag{16}$$

Set each unique weight from level one to level six as $V_1, V_2, V_3, V_4, V_5, V_6$ as Figure 8. Then in each level of the wavelet decomposition, λ' is the only variable to control the enhancement.

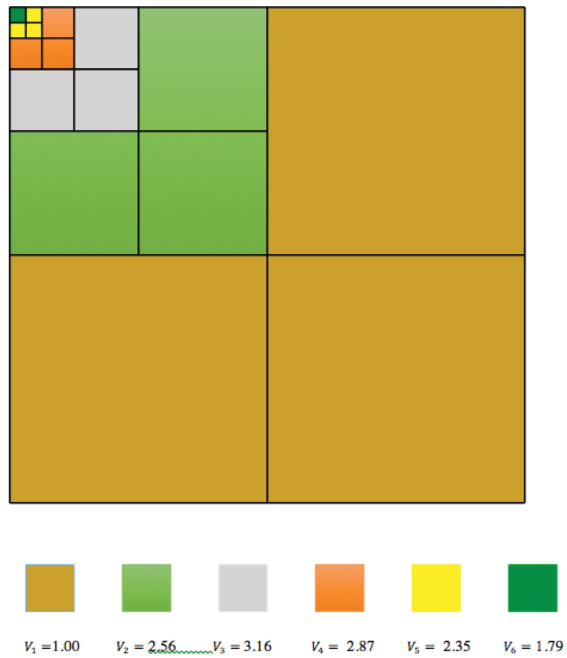


Figure 8. Each unique weight's value in a five-level wavelet decomposition

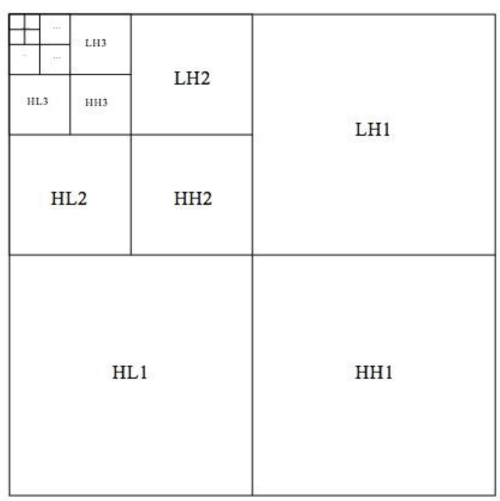


Figure 9. Five-level wavelet decomposition

In Figure 9, every detail has been given a name so that it would be much more convenient when calculating the weighting average number of each unique weight obtained from a five-level wavelet decomposition image on each scale. The first level's high and low filters to the fifth level's high and low filters are set as LL1, LH1, HL1, HH1, …, LL5, LH5, HL5, HH5.

Then

$$\bar{\mathrm{c}}_{\mathrm{N}}^{\mathrm{k}}(m,n) = \nu_{\mathrm{N}}^{\mathrm{k}}(m,n)\mathrm{c}_{\mathrm{N}}^{\mathrm{k}}(m,n) \quad (17)$$

$\bar{\mathrm{c}} = \left\{\bar{\mathrm{c}}_{\mathrm{N}}^{\mathrm{k}}(m,n)\right\}$ is the contrast of the original image. Through the N^{th} subband components $\mathrm{A}_{\mathrm{N}}(m,n), \mathrm{D}_{\mathrm{N}}^{1}(m,n), \mathrm{D}_{\mathrm{N}}^{2}(m,n), \mathrm{D}_{\mathrm{N}}^{3}(m,n)$ and equation (17), we have

$$\frac{\bar{\mathrm{D}}_{\mathrm{N}}^{\mathrm{k}}(m,n)}{\bar{\mathrm{A}}_{\mathrm{N}}(m,n)} = \bar{\mathrm{c}}_{\mathrm{N}}^{\mathrm{k}}(m,n) = \nu_{\mathrm{N}}^{\mathrm{k}}(m,n)\mathrm{c}_{\mathrm{N}}^{\mathrm{k}}(m,n) = \nu_{\mathrm{N}}^{\mathrm{k}}(m,n)\frac{\mathrm{D}_{\mathrm{N}}^{\mathrm{k}}(m,n)}{\mathrm{A}_{\mathrm{N}}(m,n)}$$

(18)

Set

$$\bar{\mathrm{A}}_{\mathrm{N}}(m,n) = \mathrm{A}_{\mathrm{N}}(m,n)$$

$$\bar{\mathrm{D}}_{\mathrm{N}}^{1}(m,n) = \nu_{\mathrm{N}}^{1}(m,n)\mathrm{D}_{\mathrm{N}}^{1}(m,n)$$

$$\bar{\mathrm{D}}_{\mathrm{N}}^{2}(m,n) = \nu_{\mathrm{N}}^{2}(m,n)\mathrm{D}_{\mathrm{N}}^{2}(m,n)$$

$$\bar{\mathrm{D}}_{\mathrm{N}}^{3}(m,n) = \nu_{\mathrm{N}}^{3}(m,n)\mathrm{D}_{\mathrm{N}}^{3}(m,n)$$

Through the equations above, we can easily get that equation (17) is satisfied.

Then, the way to get $\bar{\mathrm{A}}_{\mathrm{N-1}}(m,n), \bar{\mathrm{D}}_{\mathrm{N-1}}^{1}(m,n), \bar{\mathrm{D}}_{\mathrm{N-1}}^{2}(m,n), \bar{\mathrm{D}}_{\mathrm{N-1}}^{3}(m,n)$ was similar to equation (18):

$$\frac{\bar{\mathrm{D}}_{\mathrm{N-1}}^{\mathrm{k}}(m,n)}{\bar{\mathrm{A}}_{\mathrm{N-1}}(m,n)} = \bar{\mathrm{c}}_{\mathrm{N-1}}^{\mathrm{k}}(m,n) = \nu_{\mathrm{N-1}}^{\mathrm{k}}(m,n)\mathrm{c}_{\mathrm{N-1}}^{\mathrm{k}}(m,n) = \nu_{\mathrm{N-1}}^{\mathrm{k}}(\mathrm{m},\mathrm{n})\frac{\mathrm{D}_{\mathrm{N-1}}^{\mathrm{k}}(m,n)}{\mathrm{A}_{\mathrm{N-1}}(m,n)} \quad (19)$$

Equation (19) could be changed into:

$$\overline{D}_{N-1}^{k}(m,n) = \nu_{N-1}^{k}(m,n)\frac{D_{N-1}^{k}}{A_{N-1}}\overline{A}_{N}(m,n) \tag{20}$$

So that $\overline{A}_N(m,n)$ can be obtained:

$$\overline{A}_{K-1}(m,n) = 4 \times \left[\sum_{x,y\in Z}\hat{h}(x)\hat{h}(y)\overline{A}_N\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z}\hat{h}(x)\hat{g}(y)\overline{D}_N^1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z}\hat{g}(x)\hat{h}(y)\overline{D}_N^2\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z}\hat{g}(x)\hat{g}(y)\overline{D}_N^3\left(\frac{m-x}{2},\frac{n-y}{2}\right)\right] \tag{21}$$

Similarly, the other enhanced sub components could be obtained using the similar way in Tang's algorithm. After getting $\overline{A}_1(m,n), \overline{D}_1^1(m,n), \overline{D}_1^2(m,n), \overline{D}_1^3(m,n)$, the following equation could be used to get the enhanced image $\bar{A}_0(m,n)$:

$$\bar{A}_0(m,n) = 4 \times \left[\sum_{x,y\in Z}\hat{h}(x)\hat{h}(y)\bar{A}_1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z}\hat{h}(x)\hat{g}(y)\bar{D}_1^1\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z}\hat{g}(x)\hat{h}(y)\bar{D}_1^2\left(\frac{m-x}{2},\frac{n-y}{2}\right) + \sum_{x,y\in Z}\hat{g}(x)\hat{g}(y)\bar{D}_1^3\left(\frac{m-x}{2},\frac{n-y}{2}\right)\right] \tag{22}$$

2.3.5. The experimental results in MATLAB

To test the proposed algorithm above, experiments were done in MATLAB.

Figure 10 shows the experiment results.

Figure 10.(a) Original image; (b) enhanced image with $\lambda' = 18$; (c) enhanced image with $\lambda' = 28$; (d) enhanced image with $\lambda' = 38$. (Created by me in MATLAB platform and all rights are reserved.)

From the results, I found that after weighting the contrast manipulation factors, the output image can be enhanced. The enhancement effectiveness of the output image depends directly on the weighted contrast manipulation factor.

Chapter 3 An iPhone image enhancement application for visually impaired

With the development of modern technologies, many new devices has been available for the visually impaired, mobile devices is one of them. With mobile devices, the visually impaired can hear news rather than reading news. They can also use mobile device to enlarge text when they read. Besides the use of mobile devices, low-vision patients can also use it to see images/watch videos. However, there is generally an issue for low-vision patients when they see images/watch videos. In the past, image enhancement technologies were used to enhance videos for low-vision patients on computers. Obviously image enhancement technologies can also be used in mobile device for low-vision use. In this chapter, I will describe an iPhone image enhancement application for low-vision patients.

3.1. Development Environment

3.1.1. iPhone operating system (IOS)

IOS is a mobile operating system developed by Apple Inc and was distributed at Macworld in Jan 9th, 2007. It was originally designed for iPhone use and it was gradually applied to other IOS products such as iPod touch, iPad, Apple TV, etc.

IOS has a simple user interface, amazing features, and superior stability. It is a strong foundation for iPhone, iPad and iPod touch. The built-in technologies and features of IOS help Apple device keeps the leading position in the field of electronic products.

The architecture is divided into four levels as shown below in Figure 11:

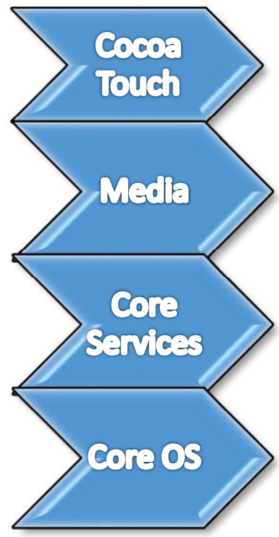


Figure 11. Four main layers of IOS structure based on the description in [36]

The Core OS layer contains comprising part, file system, network infrastructure, security features, management of energy, some device drivers, and some system-level APIs. The Core Services layer is used to visit some IOS services such as collections, address book, networking, file access, preferences, SQLite, etc. Through the Media layer, users can use various media files in the application such as recording audio and video, rendering graphics, producing basic animation. The top layer is Cocoa Touch layer. It provides a variety of useful frameworks which can be used in IOS development and most of them are related to user interface. Essentially, the Cocoa Touch layer is responsible for users' touch interaction on IOS devices.

IOS provides the built-in security for the users. Low-level hardware and firmware features are designed in the system to prevent malware and viruses. High-level hardware and firmware features are designed in the system to ensure the security of users when accessing personal information and using business data. IOS supports encrypted network communication, and it could help APP to protect the sensitive information during transmission. Meanwhile, IOS devices can be used throughout the world. Users can choose or change over 30 languages through the device. Because of the keyboard of IOS is designed based on the software, there are over 50 kinds of versions of specific language features for users to choose [36].

3.1.2. Xcode

To develop the application for image enhancement on IOS devices, Xcode development environment has been selected to be the platform. Xcode is the normal platform which is provided by Apple which can help to develop tools, provide project management, edit codes, create, execute and debug codes, assist library management, and adjust performance, etc. [38]. Xcode is necessary for developing IOS applications. Xcode is a powerful and professional development tool. People can easily use it in the simple way to perform their software development tasks.

Xcode is an integrated development environment (IDE) [38]. Xcode provides all the tools so that the developers could create and manage their iPhone source code and projects. Developers could also build their code into an executable file on the iPhone simulator or a real IOS device to run or debug their codes.

In this thesis, when building the application in Xcode, iPhone and iMac were both chosen as the simulator so that people can test this application on each IOS device. The simulator provides a local environment to test the application and ensure the application performs exactly as needed. Xcode would be told to start building after

the subjects were satisfied with the program. After that, people could connect the iPhone to the computer to run the application.

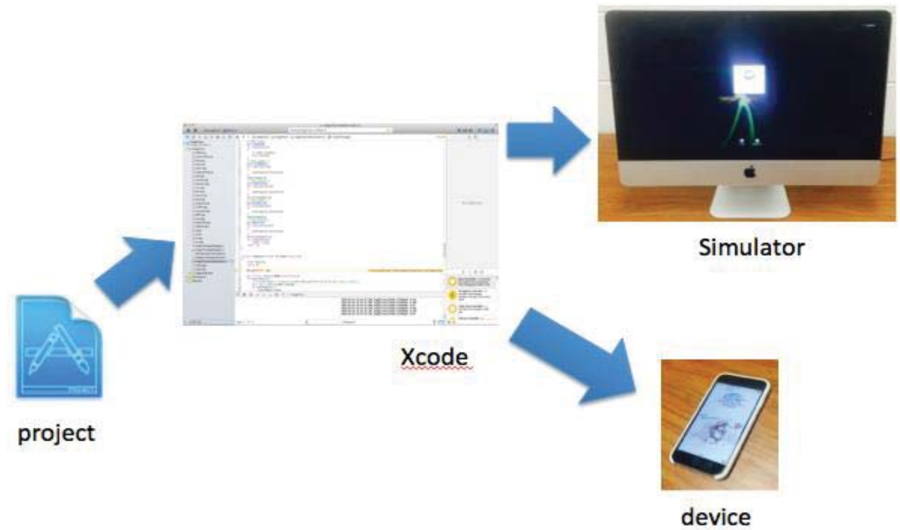


Figure 12. Simple flowchart of the Xcode project created by myself

3.1.3. Objective-C

The language which is used in IOS platforms is Objective-C. Objective-C is an extension of C, object-oriented programming language. In the early 1980s Brad Cox developed Objective-C in his company. He was very concerned with his software design and programming availability. In recent years, with the popularity of IOS device, objective-C has become one of the most popular languages in coding areas [39].

3.2. General Framework for the iPhone

3.2.1. Framework of the System

The image enhancement application consists of five main steps which is shown in Figure 14. Firstly, the user can select an image as an input. Secondly, wavelet transform is used to decompose the original image into different subbands and these subbands contain different low-frequency and high-frequency contents of the original image. Thirdly, the wavelet coefficients are modified based on the modified contrast measurement. Fourthly, the enhanced image will be obtained by an inverse wavelet transform using the modified wavelet coefficients. In the application, the most important step is to modify the wavelet coefficients because it will determine the enhancement effectiveness of the image. In the applications, the proposed vision based image enhancement algorithm developed in chapter 2 is adopted. Finally, the enhanced image will be displayed on the screen.

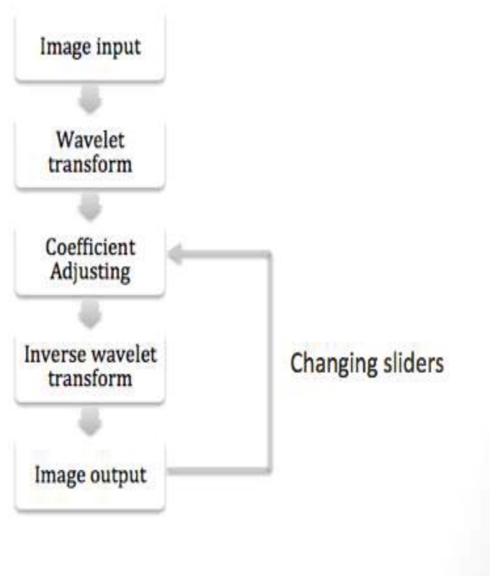
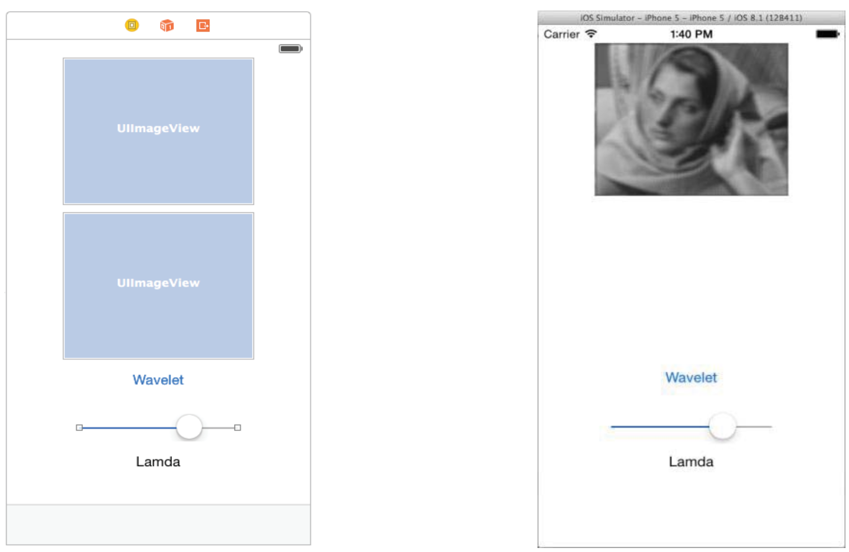


Figure 13. General framework of the Application

3.2.2. Interface of the simulation

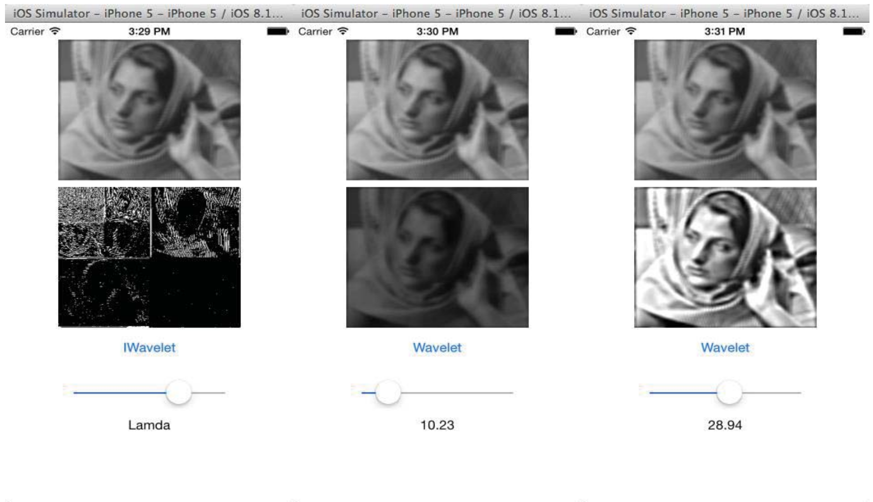
The main storyboard of the simulator is shown in Figure 14(a). Figure 14(b) shows the simulation interface.

The user can interact with the application by adjusting the slider to enhance or smooth the images so that the best visual image will be obtained for the user. Figure 15(a) shows what happens after clicking the “Wavelet” button.



(a) (b)

Figure 14. (a). Main storyboard of the simulator; (b). Simulation on PC machine



(a) (b) (c)

Figure 15. (a). Wavelet transform interface; (b). The enhanced image interface. (c). The enhanced image after adjusting the slider.

The image in the application is enhanced through the wavelet transform. After users click the "Wavelet" button, the button's name will be changed into "IWavelet" as Figure 15(b) shows. Therefore, if the button is clicked again, the image would be enhanced. When users get the enhanced image after clicking the "IWavelet" button, the image enhancement is finished and the button would be changed back to "Wavelet". If users are not satisfied with the effect of the enhanced image, they may adjust the slider below, and then repeat the steps before. A better performance of the image may show on the screen like in Figure 15(c).

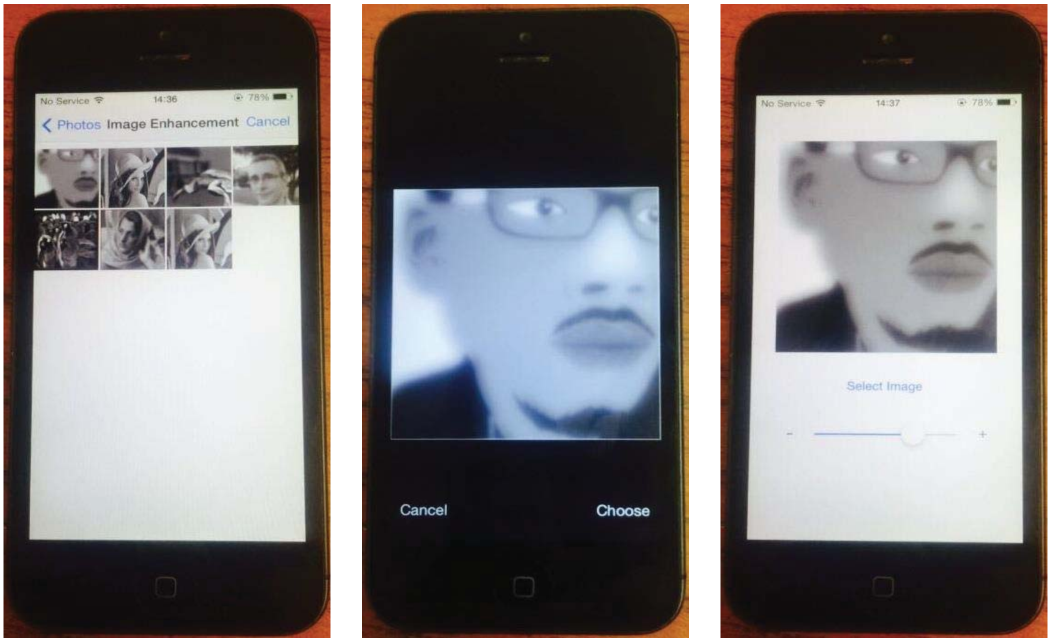
3.2.3. Mobile Interface of the Application

After successfully simulating on the Mac machine, this application was adapted for real mobile devices, as seen in Figure 16(a). The interface was similar to that on Mac machine. A logo was added when users open the application in Figure 16(b).

(a) (b)

Figure 16. (a). App icon on iPhone 5; (b). The Logo Interface when users open the application.

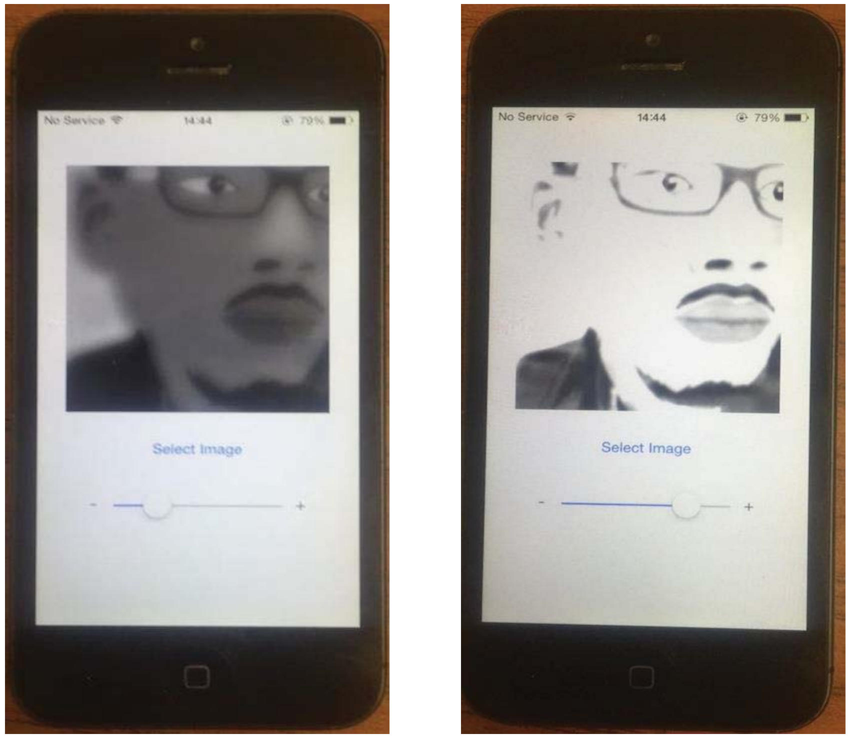
After that, users can select the image by clicking the "Select Image" button. Users will go to the image album interface as in Figure 16(a) to select which image they want to enhance. By clicking the "Choose" button in Figure 17(b), then the interface will be shown as Figure 17(c).



(a) (b) (c)

Figure 17. (a). The album Interface after clicking the “Select Image” button; (b). “Choose” button; (c). The image which is used to be enhanced.

After getting the image which is selected by users themselves, users can adjust the slider to enhance or soften the image. On the two sides of the slider, there show a “+” and a “-” icon. The two icons tell the users that after moving the slider to the right, the image will be enhanced and when moving it to the left, the image will be softened. Figure 18(a) and Figure 18(b) show the example of the actions of moving the slider to the left and moving the slider to the right.



(a) (b)

Figure 18. (a). The weakened image; (b). The enhanced image

3.2.4. Code Analysis

I implemented the proposed algorithm described in Chapter 2 in this application with the objective-C programming. In this section, some important code will be presented to explain how the image enhancement works successfully on the iPhone.

```
//read the image
- (UIImage*)colorFromImage:(UIImage*)image lamda:(float*)l{
    CGImageRef cgImage = image.CGImage;
    CGDataProviderRef provider = CGImageGetDataProvider(cgImage);
    CFDataRef bitmapData = CGDataProviderCopyData(provider);
    size_t bytesPerRow = CGImageGetBytesPerRow(cgImage);

    size_t width = CGImageGetWidth(cgImage);
    size_t height = CGImageGetHeight(cgImage);
    size_t bitsPerComponent = CGImageGetBitsPerComponent(cgImage);
    size_t bitsPerPixel              = CGImageGetBitsPerPixel(cgImage);
    NSData *datas = (NSData *)CFBridgingRelease(bitmapData);
    unsigned char *pixel = (unsigned char *)[datas bytes];


- (void)viewDidLoad
{
     [super viewDidLoad];
     image3.image =[UIImage imageNamed:@"woman.png"];
     image1.image =[UIImage imageNamed:@"woman.png"];
     isi = false;
    NSLog(@"%f",image1.image.size.height);
    NSLog(@"%f",image1.image.size.width);
    NSLog(@"%f",image3.image.size.height);
    NSLog(@"%f",image3.image.size.width);
}
```

Figure 19. Read image

The code shown in Figure 19 explains how to read the data from the image selected. As we know, processing an image is equal to processing a matrix and arrays. From the code above, each parameter of the image can be obtained.

"isi" in Figure 20 is a variable used to determine the button's value as "Wavelet" or "Iwavelet". Figure 20 also explains how to obtain the coefficients from the algorithm, turning it into the slider's value. The slider's setting is shown as Figure 21. The setting determines the slider's digits.

```
//button's title and slider action
- (IBAction)chImge:(id)sender {
    //set 6 different coefficients to one coefficient: lamda
    float l[6],lamda;
    lamda = _slider.value;
    l[0]= 0.0266 * lamda;
    l[1]=0.068 * lamda;
    l[2]=0.084 * lamda;
    l[3]= 0.0763 * lamda;
    l[4]= 0.0625 * lamda;
    l[5]= 0.0476 * lamda;
    image2.image = [self colorFromImage:image1.image lamda:l];
    //judge the button's value
    if (!isi) {
        [sender setTitle:@"IWavelet" forState:UIControlStateNormal];
    } else {
        [sender setTitle:@"Wavelet" forState:UIControlStateNormal];
    }
    isi = !isi;
}
```

Figure 20. The button value determination

```
//slider setting
-(IBAction)slider3Changed:(id)sender{

    float valueFloat3 = _slider.value;
    //int valueInt = (int)valueFloat;
    _label3.text = [NSString stringWithFormat:@"%4.2f",_slider.value];
}
```

Figure 21. Slider setting

The code in Figure 22 is used to transform the lattice to an image object, which then generates the frame of the code shown in Figure 23.

```
//Transform to image object
CGColorSpaceRef colorspace      = CGImageGetColorSpace(cgImage);// CGColorSpaceCreateDeviceRGB();;//CGColorSpaceCreateDeviceGray();
CGBitmapInfo bitmapInfo         = CGImageGetBitmapInfo(cgImage);
CGDataProviderRef providers      = CGDataProviderCreateWithData(NULL, pixel, [datas length], NULL);

CGImageRef newImageRef = CGImageCreate (
                                        width,
                                        height,
                                        bitsPerComponent,
                                        bitsPerPixel,
                                        bytesPerRow,
                                        colorspace,
                                        bitmapInfo,
                                        providers,
                                        NULL,
                                        false,
                                        kCGRenderingIntentDefault
                                        );
UIImage *newImage   = [UIImage imageWithCGImage:newImageRef];

CGDataProviderRelease(providers);
CGImageRelease(newImageRef);
return newImage;
```

Figure 22. Obtain the image object from the lattice.

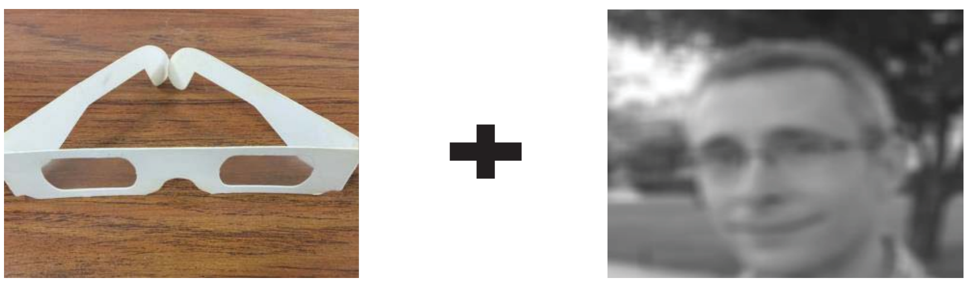
```
- (UIImage *)convertImageToGrayScale:(UIImage *)image
{
    // Create image rectangle with current image width/height
    CGRect imageRect = CGRectMake(0, 0, image.size.width, image.size.height);

    // Grayscale color space
    CGColorSpaceRef colorSpace = CGColorSpaceCreateDeviceGray();

    // Create bitmap content with current image size and grayscale colorspace
    CGContextRef context = CGBitmapContextCreate(nil, image.size.width, image.size.height, 8, 0, colorSpace, kCGImageAlphaNone);

    // Draw image into current context, with specified rectangle
    // using previously defined context (with grayscale colorspace)
    CGContextDrawImage(context, imageRect, [image CGImage]);

    // Create bitmap image info from pixel data in current context
    CGImageRef imageRef = CGBitmapContextCreateImage(context);


    UIImage *newImage = [UIImage imageWithCGImage:imageRef];

    // Release colorspace, context and bitmap information
    CGColorSpaceRelease(colorSpace);
    CGContextRelease(context);
    CFRelease(imageRef);

    // Return the new grayscale image
    return newImage;
}
```

Figure 23. Interface creation

Chapter 4. Experimental results and analysis

4.1. Tang's algorithm's experiments and results

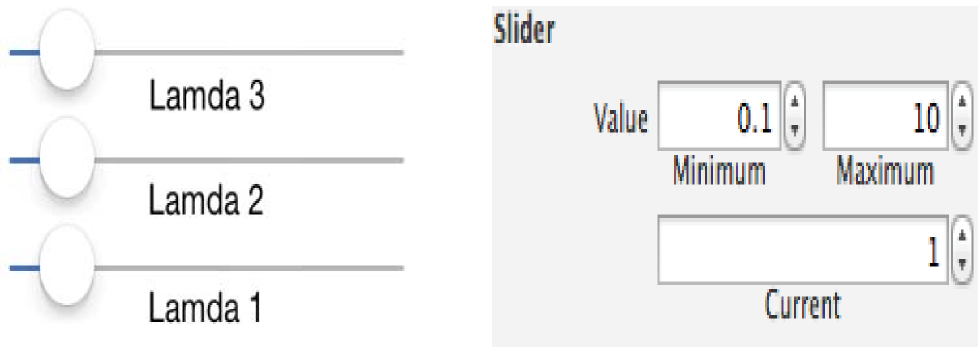
Based on Tang's algorithms, some experiments were used to perform image enhancement on blurred images. The best way of processing these experiments is to use a pair of specific glasses to watch the blurred image as shown in Figure 24(a) and Figure 24(b).



(a) (b)

Figure 24.(a) a pair of specific glasses used in the test; (b) Original blurred image

Based on Tang's algorithm, the level of the decomposition was set as three. Sliders were built in the application to obtain different effects by using different contrast manipulation factors (λ) that each λ represents each level of the subband.



(a) (b)

Figure 25.(a) Three sliders which control the values of the contrast manipulation factors ($\lambda_1, \lambda_2, \lambda_3$). (b) Set λ's initial value as one so that the output of the image is the same as the original image. The minimum of λ is 0.1, and the maximum of λ is 10.0.

Experiments were performed to confirm that the Tang's method worked well. The experiments were processed through changing the three contrast manipulation factors ($\lambda_1, \lambda_2, \lambda_3$).

Then the different enhanced performance from the experiments was observed.

Set $\lambda_1 = \lambda_2 = \lambda_3 = \lambda$, then to see different performance of different λ.

In this experiment, λ was set nine times to get nine different output images. From the figures shown above, with the increase of λ, the contrast of the image would increase.

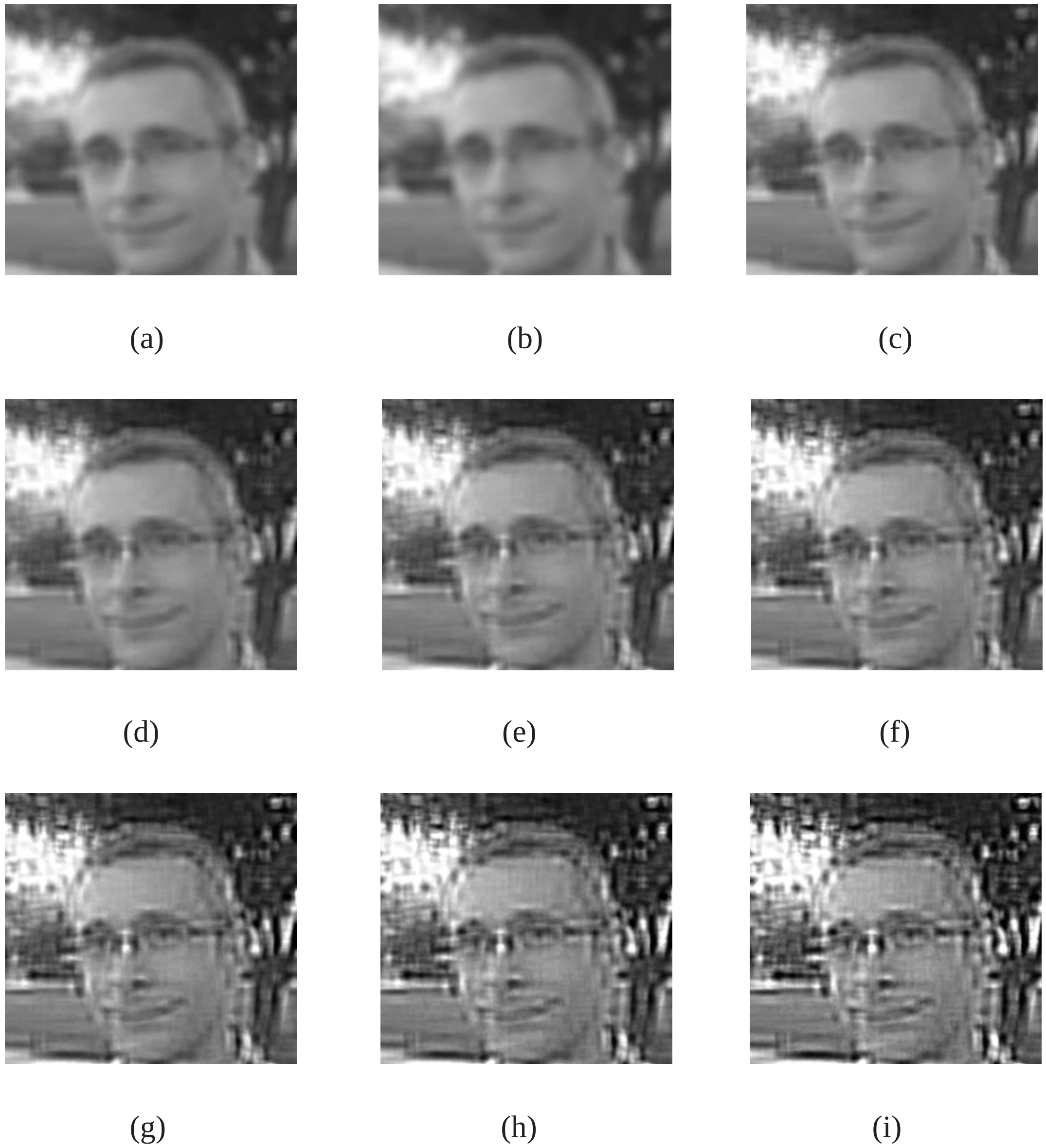


Figure 26. Nine images' different performance with different λ′s.

(a) $\lambda = 1$; (b) $\lambda = 0.5$; (c) $\lambda = 2$; (d) $\lambda = 3$; (e) $\lambda = 4$; (f) $\lambda = 5$; (g) $\lambda = 6.49$; (h) $\lambda = 8.01$; (i) $\lambda = 10$

When $0 < \lambda < 1$, the image was much more blurred than the original image, when $\lambda > 1$, the image started to be enhanced. However, according to the results' figure from Figure 26(a) to Figure 26(i), it can easily be seen that when $\lambda > 3$, the image's enhancement began to be excessive. With the increase of λ from 3 to 10, the image's noise became much more obvious. Therefore, I set the ideal changeable range of the contrast manipulation factor (λ) to enhance the blurred image effectively between 1.0 and 3.0.

Different people have different human visual characteristics (HSV). To get a better analysis of the contrast manipulation factors, five subjects were allowed to wear a pair of specific glasses to test the application based on the direct contrast enhancement algorithm. Each of the subject were allowed to pick a blurred image and use the sliders to adjust the performance of the output in the application which is shown in Figure 27.

Screenshot of all the five subjects' testing results are shown as the figures above. The result shows that images would be enhanced when $\lambda_1,\ \lambda_2,\ \lambda_3\ are$ all lager than 1. In addition, λ_3 is less likely to influence the change of the image. The value of it is larger than the other two λ's. λ_1 is much more likely to influence the effect, making the value of it closer to one.

In this case, the main algorithm was based on Tang's algorithm. The blurred image chosen was a 256*256 black image with PNG format. Because of different HSVs, the best contrast manipulation factors never exist.

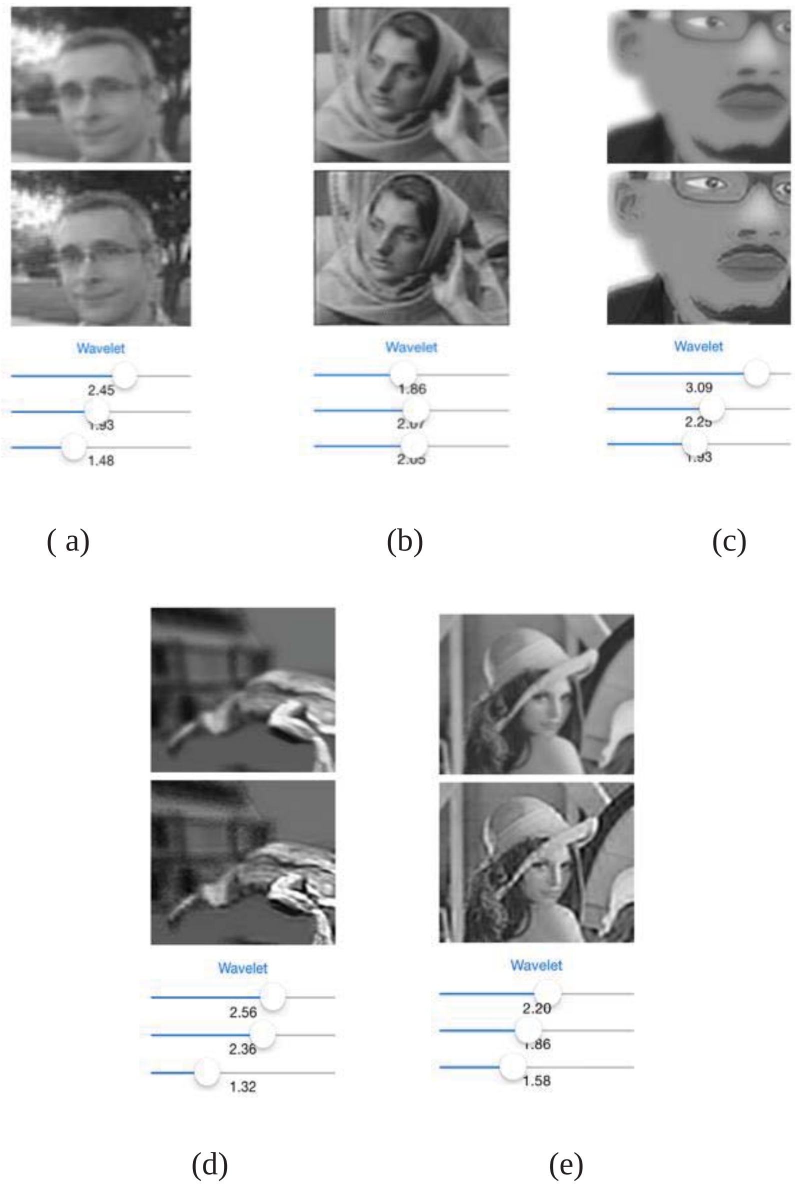
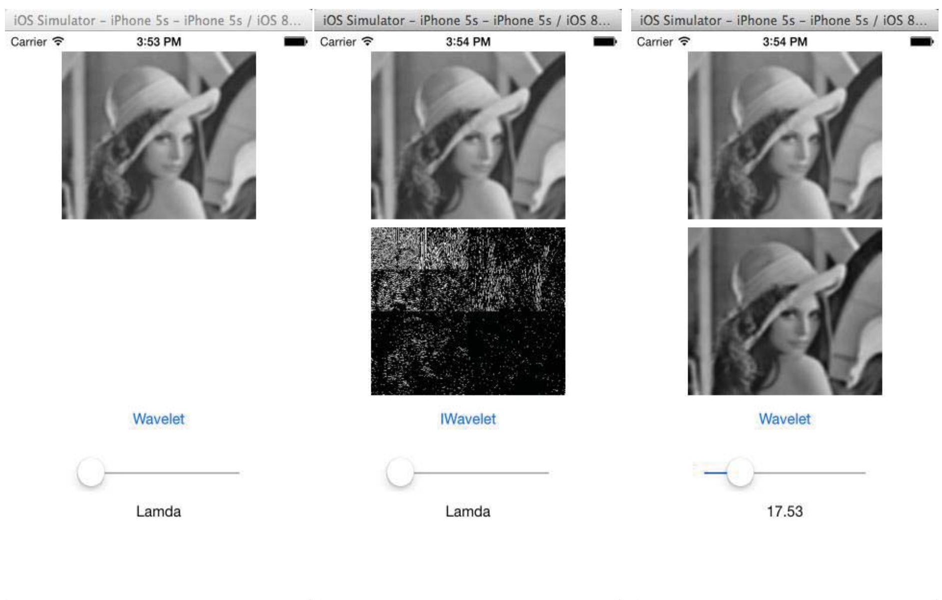


Figure 27. Five images' different performance with different λ's

(a) $\lambda_1 = 1.48,\ \lambda_2 = 1.93,\ \lambda_3 = 2.45$; (b) $\lambda_1 = 2.05,\ \lambda_2 = 2.07,\ \lambda_3 = 1.86$; (c) $\lambda_1 = 1.93,\ \lambda_2 = 2.25,\ \lambda_3 = 3.09$; (d) $\lambda_1 = 1.32,\ \lambda_2 = 2.36,\ \lambda_3 = 2.56$; (e) $\lambda_1 = 1.58,\ \lambda_2 = 1.86,\ \lambda_3 = 2.20$

4.2. A visual weighting image enhancement algorithm experiments and results

An application was developed to test the proposed algorithm whose algorithm was supposed to be improved based on Tang's algorithm. The application's interface is shown as Figure 28.



(a) (b) (c)

Figure 28. (a). The original interface after starting the application; (b). After clicking the "Wavelet" button's interface; (c). After clicking "Iwavelet" button's interface.

Through the band-average CSF Masking, those six unique weights were applied to $\frac{V_n}{\sum_{(n\epsilon Z)} V_n}$ in equation (16). Therefore, from Figure 28, we can find that there is only

one slider to control the change of the image enhancement effect in this application which could make users easier to use this app. After calculating the value of $\frac{V_n}{\sum_{(n \epsilon Z)} V_n}$ by each unique weight as shown in Figure 29, an appropriate range of lamda of the slider in this application was set from fifteen to thirty. The settings are shown as Figure 30. The value of the original image's lamda is around seventeen.

```
- (IBAction)chImge:(id)sender {
    float l[6],lamda;
    lamda = _slider.value;
    l[0]= 0.0266 * lamda;
    l[1]=0.068 * lamda;
    l[2]=0.084 * lamda;
    l[3]= 0.0763 * lamda;
    l[4]= 0.0625 * lamda;
    l[5]= 0.0476 * lamda;
    image2.image = [self colorFromImage:image1.image lamda:l];
    if (!isi) {
        [sender setTitle:@"IWavelet" forState:UIControlStateNormal];
    } else {
        [sender setTitle:@"Wavelet" forState:UIControlStateNormal];
    }
    isi = !isi;
}
```

Figure 29. Part of code which uses the result of calculation of $\frac{V_n}{\sum_{(n \epsilon Z)} V_n}$ to control the slider.

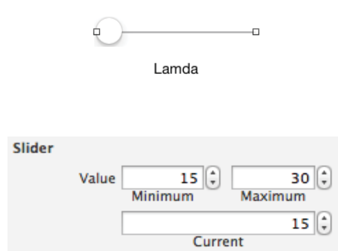


Figure 30. The slider's name set as Lamda and its altering range is set from 15 to 30 to be tested. The original value of Lamda when starting the simulator is set as 15.

To test the performance on the simulator, five subjects were invited to observe the image enhancement on this application. In the experiment, all of the subjects agreed that the image, which was altered by the sliders, has a better enhancement effect than the original image.

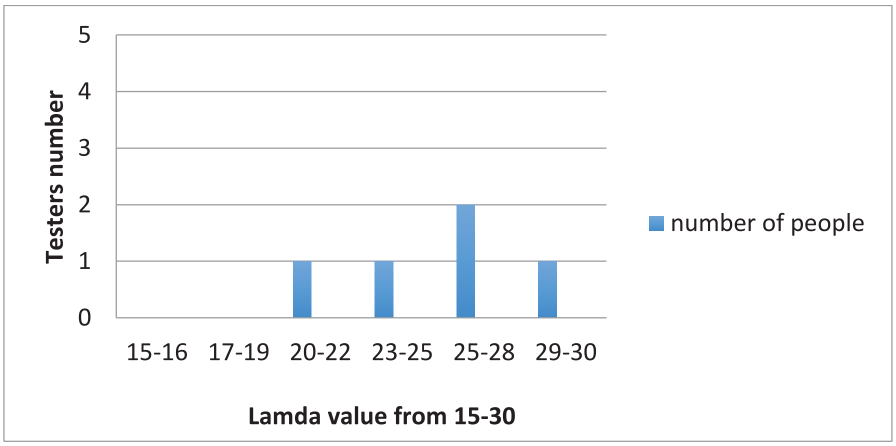


Figure 31. The chart of 5 subjects' selections of their best enhanced images through lamda from 15 to 30.

From Figure 31, we find that every subject selected his own best number of sliders to confirm their enhanced image. The value of lamda between 24.0 and 28.0 is the choice for image enhancement coefficient by most subjects.

Table1. The statistical results from 5 testers

The range of Variable (lamda)	Number of people
15-16	**0**
17-19	**0**
20-22	**1**
24-26	**1**
27-28	**2**
29-30	**1**

One of the examples from the subjects choice is shown in Figure 32. Therefore, we can conclude that this new method of weighting contrast manipulation factors with Band-average CSF Masking can be used in a mobile application.

Figure 32. The example of enhanced images from subjects

4.3. Comparison between Tang's Algorithm and the Proposed Algorithm

In this subsection, the experiments which are used to compare Tang's algorithm with the same λ, Tang's algorithm with different $\lambda's$ in different level and the proposed algorithm are described. In the experiments, five subjects were invited to do this test. The tests were done on a simulator. In the simulator, the setting for 4-inch iPhone 5s was used. Each subject was seated at a distance from the iMac that approximated the visual angle which they were accustomed to. Each subject was set to be comfortable with the environment, distance from the screen. The images used for each subject were 5-blurred-images. For statistical necessary, I labeled each image by a, b, c, d, and e. The room was dark and the luminance at the monitor was measured approximately 1.5 ft-candle. The experiment was composed of two procedures.

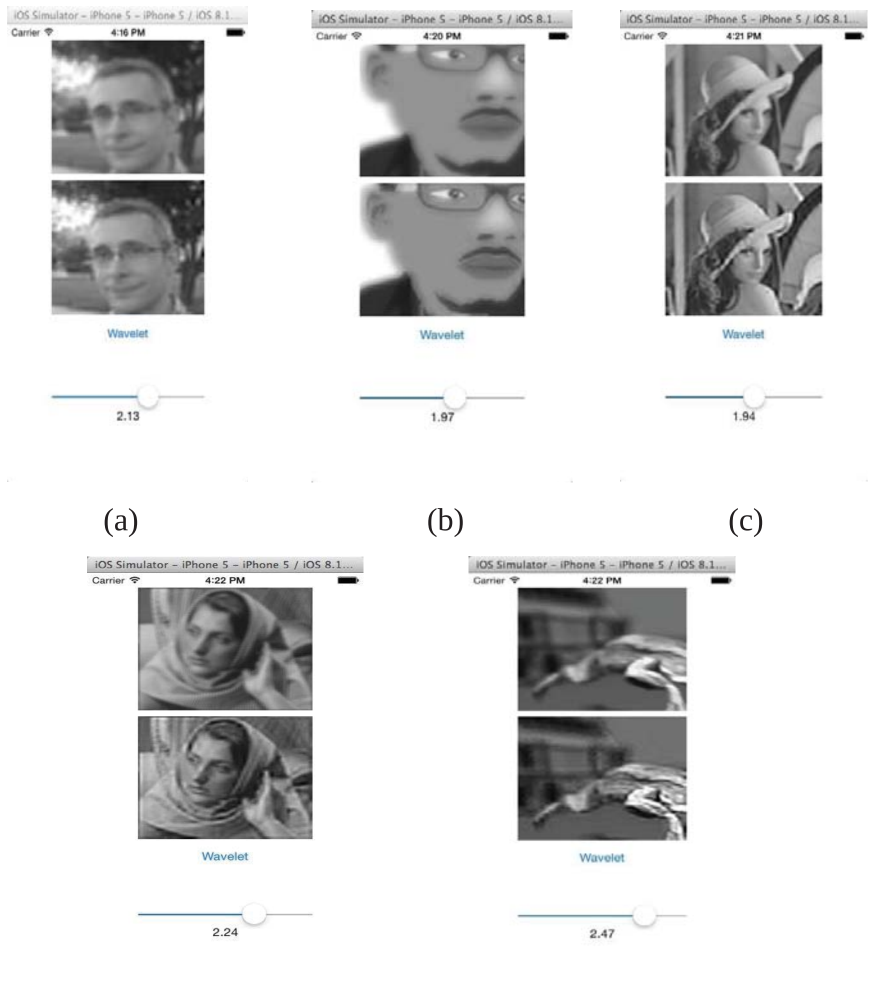
Procedure 1: Selecting the preferred enhanced images for each algorithm

In the simulation, for each algorithm, each subject was shown 5 different blurred images by turns. For each image displayed on the screen, by adjusting the sliders, the subject could select the clearest version of the image and the clearest version will be stored in the computer for future use. For two algorithms, each subject obtained 15 images, five for Tang's algorithm with same λ for all the subband, five for Tang's algorithm with different $\lambda's$ for different level subband, and five for the proposed algorithm. Figure 33, Figure 34 and Figure 35 show the examples of one of the subject's selection of the five images on the simulator.

Procedure 2: Perceived Image Quality

In this procedure, each subject was asked to grade the 15 images which he selected in procedure 1. The rating score is 1 (average), 2 (above average), 3 (good), 4(very

good), and 5 (excellent). Each subject was asked to make this evaluation subjectively. If desired, subjects could also repeat procedure 1 and make the evaluation on those 15 images multiple times. Figure 36 to Figure 40 show the evaluation of five subjects on the fifteen images selected in procedure 1.



(a) (b) (c)

(d) (e)

Figure 33. The example of one subject's selection on the simulator based on Tang's algorithm with same $\lambda's$.

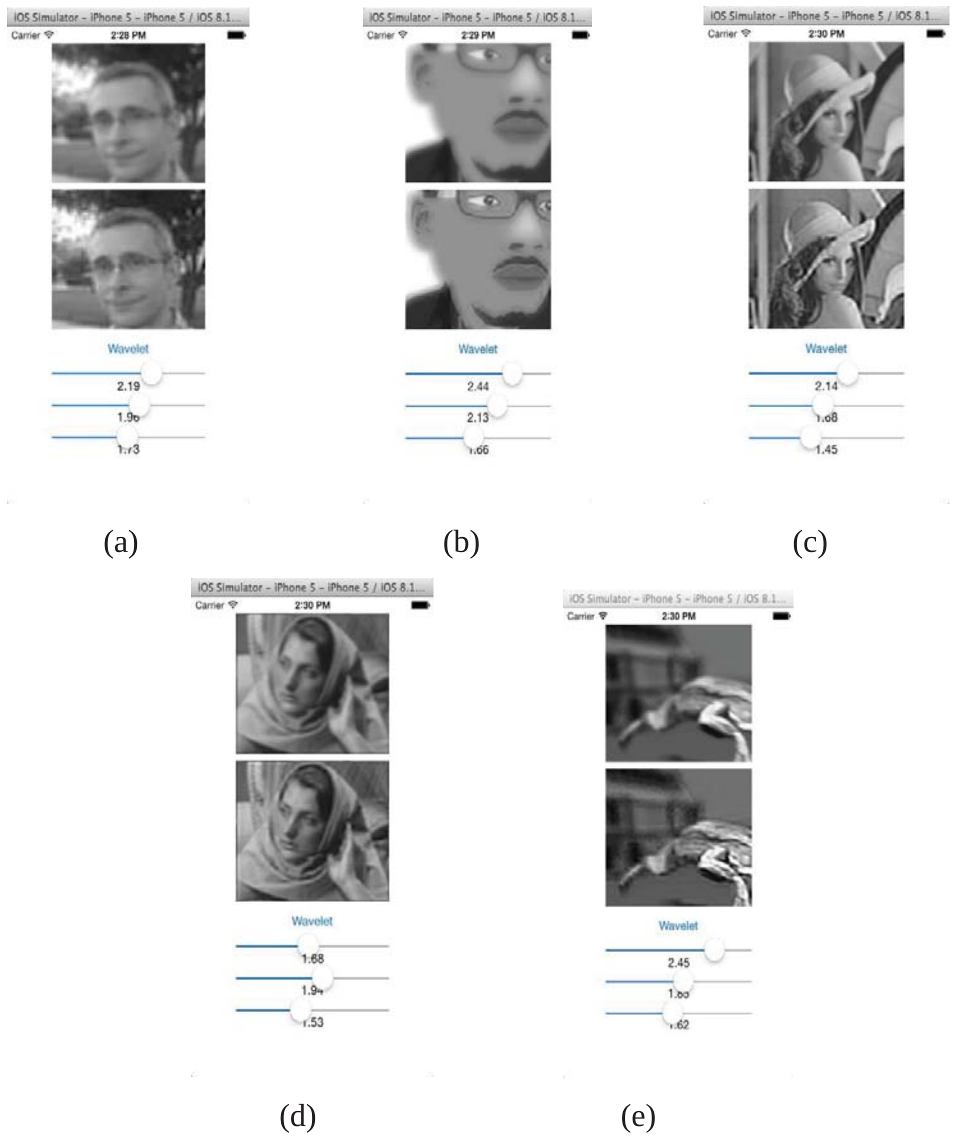


Figure 34. The example of one subject's selection on the simulator based on Tang's algorithm with different $\lambda's$.

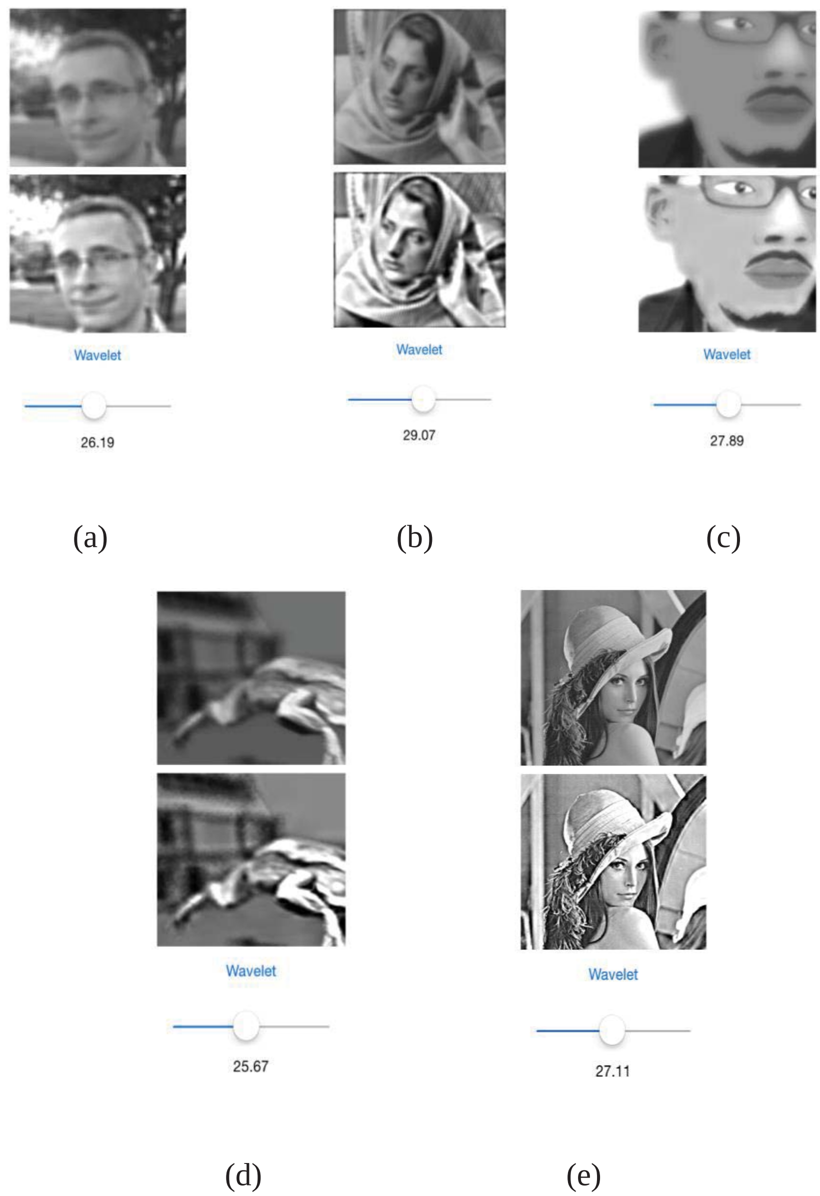


Figure 35. The example of one subject's selection on the simulator based on the proposed algorithm.

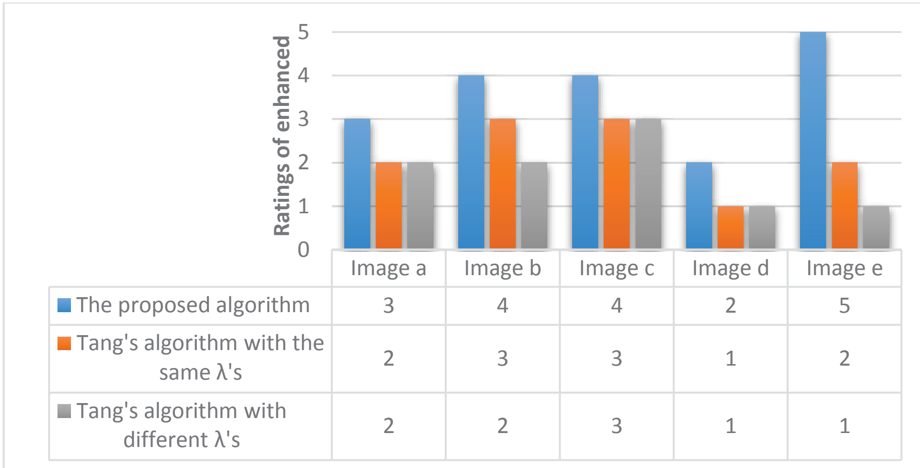


Figure 36. The evaluation ratings statistics of "subject 1" on 15 enhanced images based on two algorithms.

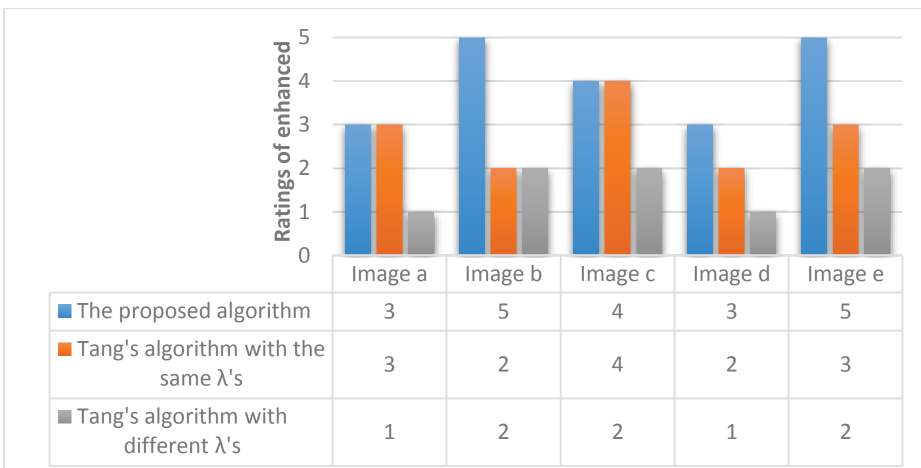


Figure 37. The evaluation ratings statistics of "subject 2" on 15 enhanced images based on two algorithms.

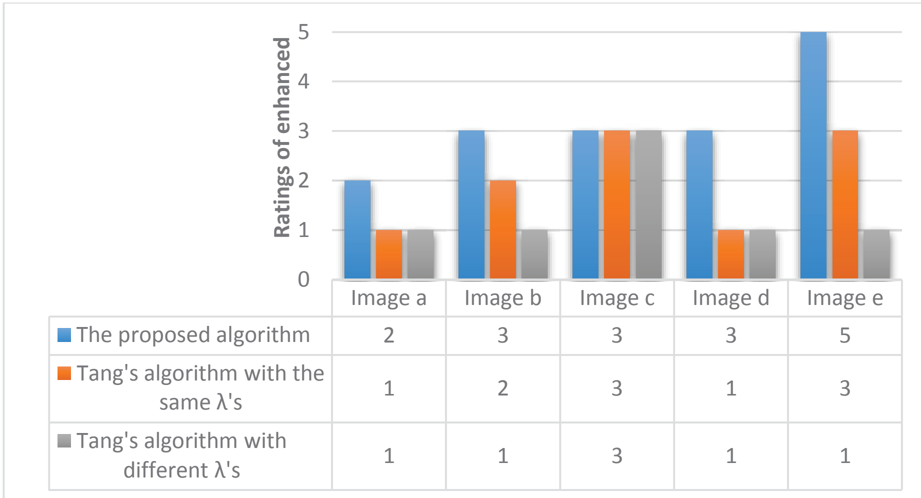


Figure 38. The evaluation ratings statistics of "subject 3" on 15 enhanced images based on two algorithms.

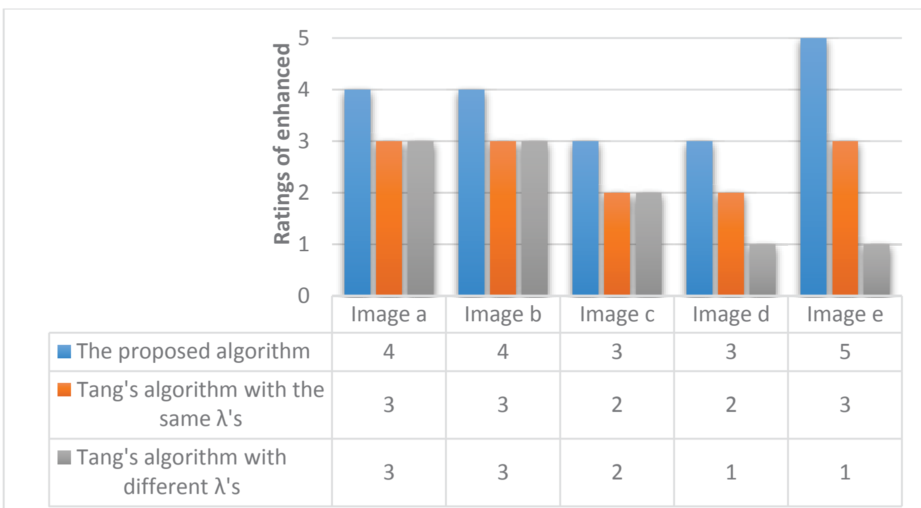


Figure 39. The evaluation ratings statistics of "subject 4" on 15 enhanced images based on two algorithms.

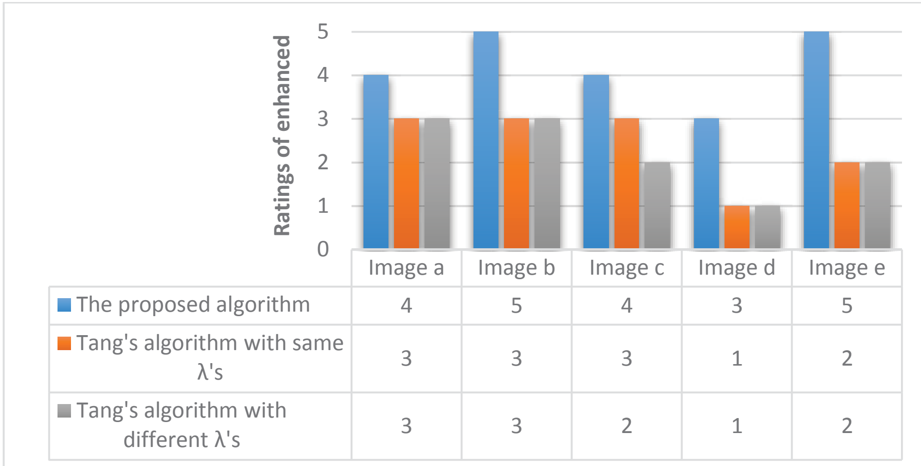


Figure 40. The evaluation ratings statistics of “subject 5” on 15 enhanced images based on two algorithms.

According to the statistic results, it can be concluded that, compared the Tang’s algorithm with same $\lambda's$ and different $\lambda's$, Tang’s algorithm with different $\lambda's$ has a little better effect on the enhanced image than Tang’s algorithm with same $\lambda's$. Compared with Tang’s algorithm, the proposed algorithm has a better effect on the enhanced image. In addition, after weighting the contrast manipulation factor in the proposed algorithm, it is much more convenient when the user adjusts the enhancement factor because only one factor is needed while there are three factors need to be adjusted in Tang’s algorithm.

Chapter 5 Summary and Future Work

In this thesis, a visual weighting image enhancement algorithm is proposed. By incorporating the human visual feature into the image enhancement algorithm, the images enhanced by the proposed algorithm would have better quality.

To help the visually impaired to get a better quality of the blurred image, in this thesis, an iPhone application with visual weighting image enhancement algorithm is developed. In the system, a blurred image and an enhanced image are both shown on the interface. Users could adjust the enhancement effect through the sliders on the interface. To test the application, experiments were done by different people. The results show the feasibility of the algorithm proposed and the potential of the system.

The algorithm proposed was also compared with Tang's algorithm in the mobile application. The experimental results show that people prefer the new algorithm proposed in this thesis rather than Tang's algorithm. The application with the new algorithm is easier to use and has better visual quality, because I set only one slider to control different contrast manipulation factors.

In this application, only gray-scale image were used. Therefore, in the future, I plan to test color images. I plan to integrate not only static images but also videos to this application to investigate its enhancement. Test using real-patients is another research direction.

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