Compression of Color Skin Tumor Images with Vector Quantization

Performing Compression in DWT and DCT Domains with a Goal of Reducing Storage Space for and Transmissions Costs of Digital Images

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The many different imaging modalities used in medicine, combined with digital imaging computer systems being widely available, and the advent of telemedicine have created the need for new image compression methods. Even well-established imaging modalities such as X-rays and ultrasound are increasingly being processed and stored in a digital format. If we need to keep multiple copies in different sites, or need to transfer these images from site to site through the Internet or certain physical channels, the need for high-performance compression algorithms to reduce storage and transmission costs is evident [1].

This research discussed in this article was implemented for compression of a set of skin tumor images, building on previous work [1-5]. One goal of this work is to develop a tool that will be useful as a physician's aid and in mass screening in settings such as shopping malls or nursing homes. As a result, a relatively large database consisting of more than 1000 digital skin tumor images has been established for the purpose of developing and testing the analysis tool. Each original image has a spatial resolution of 512 × 512 pixels, 24-bit magnitude (8 bits for each band), and occupies 786 kB of storage space.

Overview

There are two important points to be considered for designing the compression schemes: 1) compression ratio and 2) compression quality.

For the compression ratio, to meet different possible requirements, four compression ratios were designed: 4:1, 8:1, 14:1, and 20:1. For the compression quality, the compression schemes aimed at keeping as much of the pertinent information in a skin tumor image as possible, and coarsely compressing the information not significant for a dermatologist's evaluation. As shown in Fig. 1, the tumor area is most pertinent for a dermatologist, and the pattern of the skin around the tumor is an important reference, while the black edge at the bottom and the ruler are not of interest.

There is a trade off between the compression ratio and the compression quality. Normally, the higher the compression ratio, the lower compression quality it will be. The compression quality can be also affected by other factors. For example, color shifting, which is troublesome from a dermatologist's perspective, can be caused by quantization when using the principal components transform (PCT); losing contrast during compression can be enhanced by the histogram stretching techniques.

Previous research in image compression for skin tumor images using a combination of the wavelet transform and vector quantization (WVQ) [1] designed three compressions schemes, which perform vector quantization in the wavelet transform domain. The PCT was used as a preprocessing step in one of the three schemes.

The compression algorithms gave fairly good compression results. They performed both an objective test (SNRs) and a subjective test, and made comparisons with the joint photographic experts group (JPEG) and the color cell compression (CCC) algorithms [6]. According to the subjective tests, two of their three compression schemes were rated equal to or better than the CCC compression scheme. Although the JPEG was rated as the best one, one of their compression schemes was rated equal to or better than the JPEG for 19 out of 66 images. The SNRs of their compression schemes range from 17 dB to 25 dB.

For this research we wanted to extend the compression schemes to include the discrete cosine transform (DCT) and resolve some of the issues caused by preprocessing with the PCT. Also, since we were more interested in comparing the wavelet to the DCT, comparisons to older compression algorithms were not included.

Methodology and Equipment

Equipment and Development Environment

The code written for this research is part of an image-processing software package, CVIPtools, which was developed under the Solaris version of Unix [7]. The algorithms were implemented in ansi C, and the user interface was written in Tcl/Tk 8.0. The subjective tests were carried out under the Windows98 environment, using an image viewer written in the Tcl/Tk 8.0 and some DOS batch process files. To do the subjective evaluation of the compressed images, a compressed image and the original one were displayed side by side on a 17-in Sony monitor, with 1024 × 768 pixels and true-color (24 bits per pixel) display mode.

Compression Schemes — Preprocessing, Compression, and Postprocessing Algorithms

To meet different requirements, four compression ratios were designed (4:1, 8:1, 14:1, and 20:1). The compression ratios at 4:1 and 8:1 are designed to give high compression quality with relatively low compression ratios, while 14:1 and 20:1 are designed to offer relatively high compression ratios with acceptable compression quality.

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For each compression ratio, the compression was performed in both the DCT domain and the discrete wavelet transform (DWT) domain. And for each domain, two schemes were designed—with the PCT as a preprocessing step or without the PCT. The histogram stretching was used as a postprocessing step for each compression scheme. So, all together, 4(compression ratios) × 2(domains) × 2(with or without the PCT) = 16 compression schemes that were designed.

Vector quantization was used to code the transformed images. Bit allocation for the vector quantization was based largely on heuristics and on trial error, although the "optimal" bit allocation rule is used as a general guideline [8, 9]. The algorithm of finding an optimized codebook is described in a later section. Figure 2 shows the flowchart of the compression process. The decompression process basically follows the inverse sequence of the compression process.

Subjective Evaluation of the Images

The decompressed images were evaluated by three graduate students majoring in electrical engineering, two image processing professors, and one dermatologist. They were asked to grade according to the grading scale used to evaluate the quality of analog television signals [10]. This scale grades picture impairment on a scale from 1 to 6, as shown in Table 1.

To eliminate bias, the evaluations were performed blindly; i.e., observers were not informed as to which compression scheme had been applied to an image. Each decompressed image and the original image were shown side by side. Observers were allowed to examine the decompressed images from any desired distance.

Objective Measurement of the Images

The quality of the decompressed images was also measured by computing the SNRs [7]. The SNR for each image is calculated from the squared error between the original and the decompressed images.

For a digital image, which has L level in each band, the SNR between the original and the decompressed image is defined as [7]:

$$SNR_{(db)} = 10 \times \log_{10} \frac{(L-1)^2}{\frac{1}{n}\sum_{k=1}^{N}(x_k - x'_k)^2}$$

where x_k are original pixel values, and x'_k are the decompressed pixel values.

Compression Schemes

Preprocess

The Principal Components Transform (PCT)

The 24-bit color skin tumor images used in this research are composed of three color bands—red, green, and blue. Figure 3 shows each color band of skin tumor image 327n.ppm. There exist additional redundancies in such color images, since the color bands tend to be highly correlated. Using the PCT as a preprocessing technique aimed at removing such redundancies among color bands, known as an eigenvector transform, the PCT can map most of the information in R (red), G (green), and B (blue) bands into the principal band. Since the R band is typically the first band in an image file, after the PCT is performed most of the information is contained in the R band. This is because here we adopted the method that the R band is the first band in the image file, and respectively, the G band and the B band are the second and third band in the image file.

Figure 4 shows each band of skin tumor image 327n.ppm after the PCT transformation.

The Discrete Wavelet Transform (DWT)

Wavelet transforms can be described as a transform that has basis functions that are shifted and expanded versions of themselves. Because of this, the wavelet transform contains not just frequency information but also spatial information. To perform a 2-D wavelet transform on an image, one lowpass filter and one highpass filter are required. At each stage of decomposition, we perform circular convolution with the two wavelet basis vectors along the row and column directions, and then decimate both the rows and columns by two. This is done by eliminating every other sample.

As the skin tumor images are 512 × 512 pixels, the wavelet decomposition levels can range from 1 to 9. Considering the vector sets will be used for quantizing each subimage, three decompositions were used in this research, as shown in Fig. 5. We can see most of the important information is kept in the L-L band, which is the top-left quarter [1].

Figure 6 shows the wavelet transformed image for a skin tumor image 327n.ppm (log remapped for display purposes).

The Discrete Cosine Transform (DCT)

The DCT is a transformation based on cosine functions, which can transform an image from the spatial domain to the spectral domain [7]. In the transformed image, the frequencies increase from left top corner to right bottom corner. Normally, for a skin tumor image, most of the important information exists in the left top area, which is the low-frequencies area.

Figure 7 shows the DCT transformed image (log remapped). We can see the left top area is brighter than the right bottom area, due to more energy in low frequencies.

Compression — Vector Quantization

Vector quantization uses a set of subimages to represent the image. For example, given a 256 by 256 gray-scale image, we can represent it with a group of 4 by 4 subimages. To represent the image, we will have (256/4) × (256/4) = 4096 blocks to quantize. If we have 64 such 4 by 4 subimages as codebook, 6 bits will be required for quantizing each block. And if each subimage needs 4 4 × 8 = 128 bits to store, we will need 4096 × 6 + 128 × 64 = 32768 bits (4096 bytes) to store the whole image, including the codebook. Compared to a 8 bits/pixel scalar quantization, which requires 256 × 256 = 65536 bytes, we have a compression ratio at 16:1. If we do not save the codebook along with the compressed data, we can have a higher compression ratio, which is around 21.3:1 [7].

Codebook Design

Minimizing the average distortion is very difficult for a random sequence such as an image. However, we may use an iterative method to achieve minimum distortion, which can be diagramed as Fig. 8 [11]. This algorithm is referred to as the Linde, Buzo, Gray (LBG) algorithm [8], after the authors who developed it for the vector quantization, the training sequences, and the general distortion measures. The LBG algorithm and other iterative codebook design do not, in general, yield truly optimum codes. Subject to certain conditions, the LBG algorithm will yield locally optimum quantizers, but in general, there may be many locally optimum codes, and some will yield poor performance [8].

The LBG algorithm may be improved by the choice of a good initial codebook, or by trying it on several different initial codebooks. Two basic approaches to the design of an initial codebook have been developed: one can start with a simple codebook of correct size, or one can start with a small codebook size and recursively enlarge it [11].

The Design of the Vector Sets

In this research, the vector quantization was performed in the DCT and the DWT domain. As for the DCT, most of the information of an image exists in the low-frequency part of the transformed image. For the DWT transformation, three decomposition levels were used, and most of the information also exists in the low-frequency bands. To achieve good compression quality while getting a high compression ratio, a transformed image was divided into several subimages according to frequencies. Those subimages located in the low-frequency part were more precisely compressed, which keeps as much of the information as possible. And for those subimages located in the high-frequency area, they were more coarsely compressed to reduce the size of compressed data.

Algorithms were developed with and without using the PCT in both the DCT and the DWT domains. Without the PCT as a preprocessing step, identical compression was performed throughout the R, G, B bands in each subimage. In other words, each a subimage was treated as a small color image, and the same codebook was used for all three bands. So for the compression schemes without the PCT as a preprocessing step, each transformed image was divided into ten subimages, which is shown in Fig. 9 and Table 2.

For those compression schemes with the PCT as a preprocessing step, as the PCT transforms most of the information in three bands onto the R band, which was the principal band, the R band should be compressed more precisely to keep as much information as possible, and the G and B bands may be compressed more coarsely. So different vector sets were designed for R, G, and B band for each subimage. As a result, each of the R, G, and B bands in the transformed image was divided into ten subimages, which is shown in Fig. 10 and Table 3. All together, 30 subimages were used, and each of them is a gray-scale image.

The Design of the Vector Sizes and Codebook Sizes

The vector sizes and the codebook sizes directly determine the compression ratio and the compression quality. For a specific subimage, the vector sizes are defined by two factors: the vector width and the vector height, and the codebook size defines how many vectors will be saved in the codebook [11].

Normally, with the same vector size, the larger the codebook size is, the better the compression quality that can be achieved. As all the data saved in the computer are represented by bits, normally a power of 2 was chose as a codebook size. With the same codebook size, the larger the vector sizes, the larger the space required to store the whole codebook, and also the encoding speed will be much slower. So relatively small vector sizes and proper codebook sizes were chosen according to the required compression ratios and compression quality [11].

As most of the important information is located in the low-frequency area, for those compression schemes with compression ratio at 4:1 and 8:1, subimage 1 was specially quantized by vector(s) with the same sizes as the subimage; that is, those subimages were only scalar quantized pixel by pixel [7]. For the schemes with compression ratio at 14:1 and 20:1, to achieve a high compression ratio, subimage 1 (for schemes without the PCT), or subimage 1, 11, and 21 (for schemes with the PCT), were precisely vector quantized so that not much information there was lost.

In designing the vector sizes for high compression ratios, some subimages in the high frequency area, especially those in the G and B bands (for schemes with the PCT as a preprocessing step), were quantized with a codebook size of 0; that is, those subimages were totally discarded. As such, subimages located in high-frequency area are relatively large, and discarding such subimages can greatly increase the compression ratio. Considering that the human visual system is not sensitive to such high-frequency information, discarding this information did not reduce the compression quality much [7].

Postprocess

Histogram Stretching

Histogram stretching is a very popular histogram modification technique used in image enhancement for gray-level images. For an 8 bits/pixel gray-scale image, normally we have 256 gray levels available for each pixel [7]. If the gray levels of the interesting part of an image, or the whole image, are spread out over a small range, which is also called low contrast, human eyes may not see the patterns in the image well [7]. After the histogram is stretched, we can get the improved result.

Histogram Stretching with Clipping

For some images, although there are some dark pixels with gray values around 0 and some bright pixels with gray values around 255, most of the other pixels only spread out in a narrow range [7].

For such an image we can not perform the histogram stretching directly to enhance the contrast, but we can enhance such an image by a technique called histogram stretching with clipping. The histogram stretching with clipping is done by clipping some of the pixels at the high end and low end of the histogram, and stretching the other pixels, which should be most of original pixels, from 0 to 255. Figure 11 show how this technique works.

It was found that the decompressed images always showed a poorer contrast, compared to the original images. Also, there are always just a few pixels in each color band at the top end or the bottom end of the histogram. Figure 12 shows one of the decompressed images (327n.ppm, compressed in the DCT domain, 8:1) without any postprocessing steps, and its histogram distribution. We can see there is some contrast lost in the decompressed image.

This research performed the histogram stretching with clipping as a postprocessing step on each color band. 0.25% of all the pixels in each band were clipped at both the top end and the bottom end of the histogram. Figure 13 shows the decompressed image after such a postprocessing step as well as its histogram distribution. We can see that the contrast of the decompressed image after such a postprocessing step looks better.

The SNRs of the decompressed image without postprocessing, shown in Fig. 12, is 22.2 dB, while the SNR of the decompressed image after the postprocessing step, shown in Fig. 13, is 30.5 dB. Research showed such a postprocessing step can enhance the SNRs by 5~8 dB.

Results and Analyses

In this research, both subjective and objective tests were performed for all the compression schemes. Sixty-five skin tumor images were used in the tests.

Results and Analyses for the Schemes with Compression Ratio 4:1

Figure 14 shows the subjective evaluation for the compression schemes at 4:1. It is shown that the compression quality among the four schemes is very similar—the best is just around 0.45 better than the worst, but overall the professionals ranked the images one grade lower than the students did.

The professionals ranked the DWT as the best one, and the DCT with the PCT as a preprocessing step as the worst one. Inconsistently, students ranked the DCT as the best one while the DWT, which was ranked as the best one by professionals, as the worst one. As both the professionals and the students gave good evaluations to the DCT, the DCT is thought to be the best one, and the DCT with the PCT as a preprocessing step is thought to be the worst one, and the difference between them is only 0.3 of a grade.

Figure 15 shows the objective measurements (SNRs). We can see that the DWT and the DCT show the two highest SNRs, and the DCT with the PCT as a preprocessing step shows the lowest one, which is consistent with the professionals' evaluation. Similar to the subjective evaluation, the difference among the SNRs of the four schemes is not obvious, and the highest average is only 2.9 dB higher than the lowest one.

As the compression ratio (4:1) is relatively low, all the R, G, and B bands did not lose much information during the compression. So the advantage of performing the PCT as a preprocessing step was not obvious. If the vector sizes and codebook sizes used in the schemes with the PCT as a preprocessing step can be optimized more, the compression quality may be enhanced to be a bit better than those schemes without the PCT. Figure 16 shows the 327n.ppm image compressed at 4:1.

Results and Analyses for the Schemes with Compression Ratio 8:1

Figure 17 shows the subjective evaluations for the compression schemes at 8:1. It is shown that both the professionals and students ranked the DCT with the PCT as a preprocessing step as the worst one. The professionals ranked the DCT as the best one, while the students ranked the DWT with the PCT as a preprocessing step as the best one, which is ranked by professionals as the third best one. Similar to the evaluations for 4:1, the difference among the four schemes is not significant, but the professionals ranked the images around 0.6 of a grade worse than the students did. Considering both the professionals' and the students' evaluations, the DCT and the DWT with the PCT as a preprocessing step are thought to be the best two, and the DCT with the PCT as a preprocessing step is thought to be the worst one.

Figure 18 shows the objective measurements (SNRs). The DWT with the PCT as a preprocessing step showed the highest SNR, while the DWT, which was ranked as the second best by the professionals, shows the lowest SNR. Similar to the subjective evaluations, the average SNRs of the four schemes do not differ much, and the highest is only around 1 dB higher than the lowest one. And since the standard deviations are similar, it can be concluded that no significant difference is found by this measure. As the compression ratio (8:1) is still relatively low, the advantage of performing the PCT as a preprocessing step still was not obvious. Figure 19 shows the 327n.ppm image compressed at 8:1.

Results and Analyses for the Schemes with Compression Ratio 14:1

Figure 20 shows the subjective evaluations for the compression schemes at 14:1. The professionals and students gave consistent evaluations among the four schemes. Both ranked the DCT with the PCT as a preprocessing step as the best one, and the DWT as the worst one, around one grade worse than the best one. The difference of the compression quality among the four compression schemes is more obvious than with the 4:1 and 8:1 compression schemes.

Figure 21 shows the objective measurements (SNRs). Consistent with subjective evaluation, the DCT shows the highest SNR, and the DWT showed the lowest, which is around 1.9 dB lower than the highest.

As the compression ratio (14:1) is relatively high, more information in each color band was lost during compression. The PCT did provide a good way to achieve a high compression ratio while keeping as much information as possible by mapping most of the information in three color bands into the principal band. In both the subjective evaluation and the objective tests, we can see that the two schemes with the PCT as a preprocessing step show the two best qualities. The DCT with the PCT as a preprocessing step is ranked around 0.6 of a grade better than the DCT by the subjective evaluations, and it shows 0.7 dB higher than the DCT in SNRs tests. The DWT with the PCT as a preprocessing step is ranked around 0.8 of a grade better than the DWT by the subjective evaluations, and it shows 1.4 dB higher than the DWT in SNRs tests. Figure 22 shows the 327n.ppm image compressed with the schemes at 14:1.

Results and Analyses for the Schemes with Compression Ratio 20:1

Figure 23 shows the subjective evaluations for the compression schemes at 20:1. The professionals ranked the DCT with the PCT as a preprocessing step as the best one, while the students ranked the DWT with the PCT as a preprocessing step as the best one. But both of them ranked the DCT as the worst one because of the bad color shifts, more than one grade worse than the other three schemes. We can see the compression quality among the four schemes at 20:1 spread out in a relatively large range—the DCT with the PCT as a preprocessing step maintained most of the information and produced acceptable compression quality, while the DCT caused unacceptable color shifts and the compression quality is much worse.

Figure 24 shows the objective measurements (SNRs). Consistent to the subjective evaluations, the DCT with the PCT preprocessing step and the DWT with the PCT preprocessing step show the highest two SNRs, and the DCT shows the lowest SNR, around 6 dB lower than the other schemes.

As 20:1 is the highest compression ratio in this research, the advantage of using the PCT as a preprocessing step is very obvious. As we have seen, the DCT without the PCT as a preprocessing step showed very bad color shift, while the DCT with the PCT as a preprocessing step is ranked by the professionals as the best one and showed the highest SNR. Figure 25 shows the 327n.ppm image compressed at 20:1.

Comprehensive Analysis of the Four Compression Ratios

Figure 26 and Fig. 27 show both the professionals' and students' subjective evaluations of the four schemes along with the compression ratios. For the curve of the DWT, we can see that the compression ratio of 14:1 even showed worse evaluations than 20:1. We believe the reason for this is that when the evaluators were grading the 20:1 compressed images, compared to the other compression schemes that showed relatively low quality, evaluation for the DWT was psychologically biased. At the compression ratio of 4:1, all four compression schemes showed similar compression quality, but as the compression ratio goes higher and higher, the compression qualities among the four schemes are more and more different, and using the PCT as a preprocessing step shows more and more enhancement in the compression quality. At 4:1, the two schemes without the PCT as a preprocessing step even show a bit better compression quality than the two schemes with the PCT as a preprocessing step, but at 20:1, the DCT with PCT as a preprocessing step shows much better compression quality than the DCT.

Figure 28 shows the SNRs of the four schemes along the compression ratios. We can see that the compression quality of the scheme with the DCT goes down quickly when the compression ratio goes up—the SNR at 20:1 is 13 dB lower than 4:1; while the compression quality of the DCT with the PCT as a preprocessing step does not go down so much, only 4.5 dB lower.

Conclusions and Future Work

The compression schemes designed achieved good compression qualities, except for the DCT at 20:1, which caused unacceptable color shifts. At the compression ratio of 4:1, the two schemes without the PCT as a preprocessing step show even a little bit better compression quality than the two schemes with the PCT as a preprocessing step. If the codebook sizes can be optimized more, better compression quality can be achieved for the schemes with the PCT as a preprocessing step. At the compression ratios of 14:1 and 20:1, optimized wavelet transform vectors can be investigated to reduce the ringing artifacts more.

In this research, the codebook is saved as the float data type, which uses 4 bytes to store each number. Higher compression ratios can be achieved by using a less-precise data type to save the codebook, such as the byte data type, which uses 1 byte to store each number. If the codebook is saved as byte type, the compression quality will not be changed much, while the sizes of the codebooks will be reduced much. Such an improvement can enhance the compression ratio 1.5~2.5 times higher, while keeping the compression quality almost the same. This is because usually the data range of the byte can accommodate the data range of most of the transformed images. Thus, we can remap the float data type of the codebook (after the transforms) into the byte data type before saving the codebook. Also with vector quantization in the DCT domain, and using byte data type, we can further improve the compression quality by removing the DC term before doing the transform and keeping the DC term separately in the compressed image file. This is because after doing DCT transform, the value corresponding to the DC term is always far away from the others. Thus, by removing the DC term, we can improve the data precision when remapping the float data type into the byte data type.

The color shift is a problem for this research. Here, compression was performed on a group of skin tumor images, and any color shift can be critical to a dermatologist's analysis. For other possible uses, such as high-definition digital television (HDTV), small color shifts may not be as problematic. Here, a color shift is most obvious in the compression schemes without the PCT preprocess at high compression ratios, such as the DCT at 20:1. As the compression was performed more coarsely at high compression ratios, if one of the three color bands lose, or retain, much more information than the other two bands, the color shift will appear. The PCT is a good way to solve this problem. We can see that the compression schemes with the PCT as a preprocessing step show much less color shift. The reason is the PCT transforms almost all the information in the three bands into the principal band. The histogram stretching with clipping was used as a postprocessing step in this research, which enhanced the SNRs. However, in the subjective evaluations, in those bright areas with pixel values higher than 240, some detailed patterns could not be seen clearly. The reason is that for the human visual system, gray levels from 240 to 255 almost look the same, so even if the information there was not lost, it does not look clear to human visual system [7]. Further research can be investigated for this problem. One of the possible methods is to perform an "adaptive clipping," which is to adjust the amount of the pixels to be clipped according to the specific histogram of an image. Such a method was not investigated in this research.

There may be many possible enhancement methods for this research, but by optimizing the vector sizes and codebook sizes, the preprocessing techniques, and the postprocessing techniques are the three primary areas for further enhancements.

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PLEASE SUPPLY BIOS AND ADDRESS FOR CORRESPONDENCE

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Table 1. Subjective Measurement Scales	
Grades	Comments
1	Imperceptible impairment
2	Just perceptible impairment
3	Perceptible but not disturbing
4	Somewhat objectionable impairment
5	Definitely objectionable impairment
6	Extremely objectionable impairment

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19. (a) 8:1 in the DCT domain. (b) 8:1 in the DWT domain. (c). 8:1 in the DCT domain with the PCT preprocess. (d) 8:1 in the DWT domain with the PCT preprocess.
20. The subjective evaluation for the compression schemes at 14:1.
21. The objective measurement for the compression schemes at 14:1.
22. (a) 14:1 in the DCT domain. (b) 14:1 in the DWT domain. (c) 14:1 in the DCT domain with the PCT preprocess. (d) 14:1 in the DWT domain with the PCT preprocess.
23. The subjective evaluation for the compression schemes at 20:1.
24. The objective measurement for the compression schemes at 20:1.
25. (a). 20:1 in the DCT domain. (b) 20:1 in the DWT domain. (c) 20:1 in the DCT domain with the PCT preprocess. (d) 20:1 in the DWT domain with the PCT preprocess.
26. Professionals' subjective evaluation for four compression ratios.
27. Students' subjective evaluation for four compression ratios.
28. The SNRs of the four compression ratios.

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The decompressed images were evaluated by three graduate students majoring in electrical engineering, two image pro-

Table 2. Sizes of 10 Subimages										
Subimage	1	2	3	4	5	6	7	8	9	10
Width	64	64	64	64	128	128	128	256	256	256
Height	64	64	64	64	128	128	128	256	256	256
Number of Bands	3	3	3	3	3	3	3	3	3	3

Table 3. Sizes of 30 Subimages										
Subimage	1	2	3	4	5	6	7	8	9	10
Width	64	64	64	64	128	128	128	256	256	256
Height	64	64	64	64	128	128	128	256	256	256
Number of bands	1	1	1	1	1	1	1	1	1	1
Subimage	11	12	13	14	15	16	17	18	19	20
Width	64	64	64	64	128	128	128	256	256	256
Height	64	64	64	64	128	128	128	256	256	256
Number of bands	1	1	1	1	1	1	1	1	1	1
Subimage	21	22	23	24	25	26	27	28	29	30
Width	64	64	64	64	128	128	128	256	256	256
Height	64	64	64	64	128	128	128	256	256	256
Number of bands	1	1	1	1	1	1	1	1	1	1

cessing professors, and one dermatologist.

To achieve good compression quality while getting a high compression ratio, a transformed image was divided into several subimages according to frequencies.

We can see that the compression quality of the scheme with the DCT goes down quickly when the compression ratio goes up.