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# DCTlab: educational software for still image compression and its application in a digital television course

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**Abstract** Current standards for the compression of still and moving images use Discrete Cosine Transform (DCT) to remove spatial redundancy in images. Students specialising in image and video system engineering need to know why DCT is important in their field of interest and to understand the influence of DCT-based image compression on picture quality. Therefore, we have developed educational software, called DCTlab, that helps students to analyse DCT application in still image compression systems. This paper describes software characteristics, its application in a digital television course and learning outcomes.

**Keywords** digital television; discrete cosine transform; image compression; picture quality

The applications of imaging are numerous and include manufacturing, entertainment, remote sensing, publishing, interactive services, multimedia and the transfer of image data over communication lines. In many systems, including digital television systems, compression of image and video data should be used for efficient storage and transmission.<sup>1</sup> Signal compression algorithms reduce the bit rates, by exploiting the inherent redundancy of the image and video signal, and also balancing the quality of the output signal to emphasise what is important to the human visual system (HVS).

Two widely used digital image compression techniques are predictive coding and transform coding. Predictive schemes compress each pixel by quantizing the difference between a predicted value (based on its coded history) and its actual value. Transform coding, particularly using the Discrete Cosine Transform (DCT)<sup>2</sup> has been established as one of the most powerful approaches. DCT is today's most widely used image compression technique<sup>3</sup> and current standards for the compression of still (JPEG<sup>4</sup>) and moving (MPEG-1,<sup>5</sup> MPEG-2<sup>6</sup>) images use DCT. The most important standard for digital television systems is MPEG-2.

In a DCT compression system, images are first separated into square blocks of typical size  $8 \times 8$ . Each of the blocks is DCT transformed, resulting in another  $8 \times 8$  block, whose coefficients are then quantized and coded. Most of the quantized DCT coefficients end up having zero value, resulting in high compression. Applying inverse DCT to the quantized DCT coefficients recovers an approximate version of the original block. Using these techniques, each still image can be compressed by itself to a significant degree. *Intraframe* video compression can use such techniques by independently coding each of the pictures of moving images. An additional compression can be achieved by use of *interframe* video compression, where the temporal redundancy (which exists

between frames) can be removed. In principle, anything that already exists in the previous frame need not be transmitted again — it can just be copied by the receiver from a stored copy of the previous frame and translated by a motion vector to achieve the predicted frame. The difference between predicted and actual frame is compressed like a still image, using DCT coding. Such a scheme is called *hybrid motion compensated predictive/DCT coding*. The above methods are used in the MPEG-1 and MPEG-2 standards. It means that MPEG compression uses all the concepts of JPEG including DCT, quantizing and entropy coding, and it adds motion compensation to compress interframe redundancy.

DCT is included in many aspects of digital television storage and transmission systems and it is very important for students to have a good knowledge of DCT. Therefore, we have developed educational software, called DCTlab, that helps students to understand how DCT works in still image compression systems, making sure that picture fits the system, or conversely, that the system can handle the picture. Using DCTlab students can learn a lot about image frequency analysis, influence of image content on compression results, correlation between image content and picture quality, and correlation between objective and subjective picture quality. Students can analyse each step of the DCT image compression algorithm and can see the effects of changes in compression algorithm on image quality. Students can learn how to obtain a balance between compression ratio and image quality.

We have found that the use of such educational software is very useful as a complementary tool in our digital television course. This is the undergraduate elective course taught at the Faculty of Electrical Engineering and Computing, University of Zagreb, in Croatia. The course deals with: digital coding of composite and component TV signals, video compression techniques and standards, digital video broadcasting, digital video tape recording formats, interactive television, HDTV and picture quality measurements. Previous attendance at a television course is a prerequisite for the digital course. The students should have a good knowledge of the basic principles of video and conventional analogue TV systems. All basic information about the television course is available on the Web page: <http://www.vcl.fer.hr/tv/>, and about the digital television course on Web page: <http://www.vcl.fer.hr/dtv/>. The DCTlab software is also available on this Web page.

### **DCTlab: software description**

DCTlab is educational software with a didactic objective and therefore it combines theory and practice in a very convenient way. The basic theory of DCT application in still image compression is included in a specially developed and designed DCTlab Help file that can be first presented to the students, Fig. 1. It is divided into four parts: 1. Compression of Still Images, 2. Discrete Cosine Transform, 3. JPEG Compression, 4. Picture Quality Assessment.

DCTlab is written in a MATLAB environment. Figure 2 shows a typical

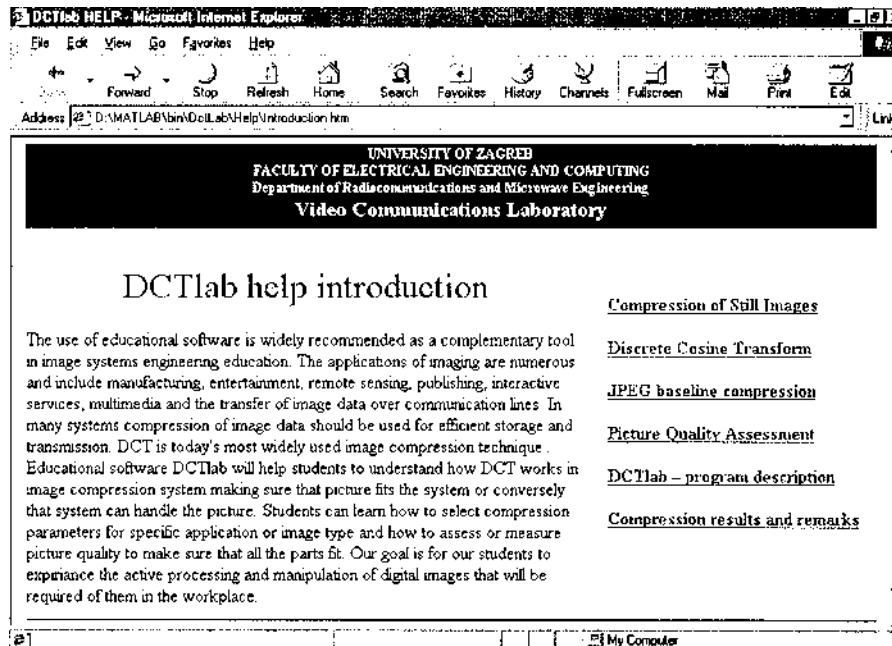


Fig. 1 Basic theory about DCT in image compression is included in DCTlab Help files.

DCTlab window with all previously performed steps from original to reconstructed image. The main window is divided into parts, which represent steps in JPEG image compression. DCTlab works with Windows bitmap images. It operates on single component (greyscale) images. However, JPEG can work with colour images that consist of multiple components. Greyscale image is a special case of a single component image. Colour image can be approximately regarded as multiple greyscale images. The use of greyscale images in DCTlab is an appropriate simplification for overview purposes, because all processes specified for greyscale image can operate on each component of colour image independently. The dimensions of the input image are restricted to  $256 \times 256$  or  $512 \times 512$  pixels. The original image is displayed in the left frame and the reconstructed image in the right frame. Any  $8 \times 8$  pixel block can be interactively selected in the original image and its values can be examined in the table next to it. The input image is divided into square blocks. The size of block can be set to:  $4 \times 4$ ,  $8 \times 8$ ,  $16 \times 16$ , ...,  $512 \times 512$ . DCT is performed on each block independently and results can be examined in an associated frame and table. By applying DCT to the whole image, one-dimensional frequency analysis of DCT coefficients can be performed and the spectral activity of the input image evaluated and presented in a new window.

To achieve compression, a threshold value for DCT coefficients can be set. This means that all coefficients below the threshold are set to zero. After that,

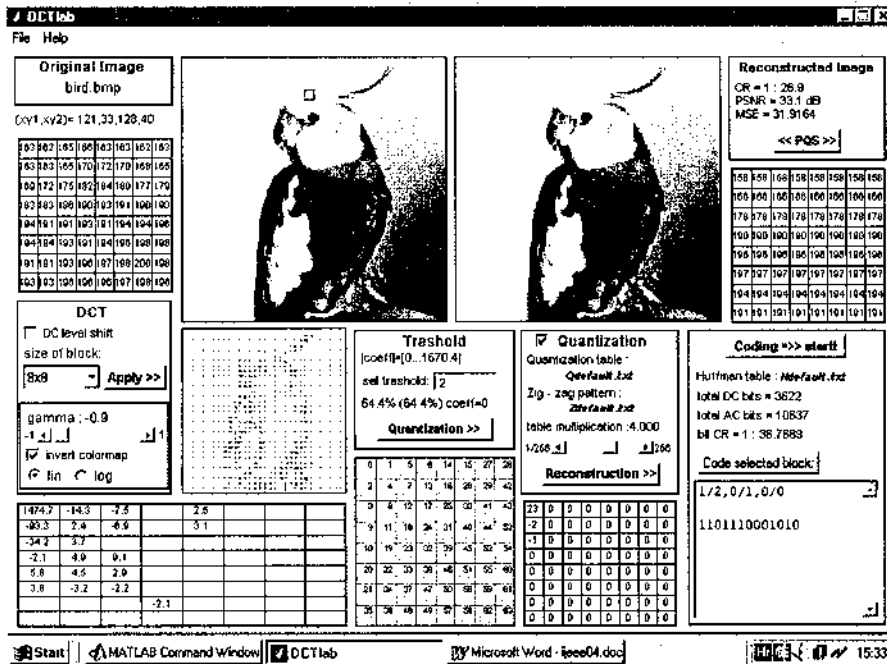


Fig. 2 DCTlab window.

the compression ratio (CR) can be computed as a ratio of the number of non-zero coefficients to the number of all pixels in the image. For an  $8 \times 8$  block size (typical for JPEG), quantization and coding can be applied. The CR can be adjusted by changing the values in the quantization table, which are scaled by a user-defined constant (table multiplication). The quantized DCT coefficients are then linearised in a zigzag scanning order and entropy Huffman coding is performed. Quantization tables, zigzag patterns and Huffman tables are user-definable. During decompression the inverse DCT is taken to create the reconstructed image. Students can select either the reconstructed image or reconstruction error image in the right frame and they can assess visual picture quality. For each compression ratio, image quality can be evaluated objectively (peak signal-to-noise ratio, PSNR and mean square error, MSE) or subjectively (picture quality scale, PQS). Students can change compression parameters and compare the differences between quality measures.

The traditional objective measures (PSNR and MSE) have long been recognised as inadequate because of their low correlation with human visual perception.<sup>7</sup> In fact, in image compression systems, the truly definitive measure of image quality is perceptual quality.<sup>8</sup> Therefore, in addition to the commonly used PSNR and MSE, we chose to use a perception-based subjective evaluation, quantified by PQS.<sup>9</sup> PQS is a perception-based quantitative distortion measure. The PQS has been developed for evaluating the quality of compressed images.

It combines various perceived distortions in image coders into a single quantitative measure and it correlates well with the subjective evaluation. The PQS method uses the five-grade impairment scale (5-imperceptible, 4-perceptible, but not annoying, 3-slightly annoying, 2-annoying, 1-very annoying) which is developed for subjective evaluation.<sup>10,11</sup> In DCTlab PQS is computed using a separate program, which can be started from the main DCTlab window. The PQS program (written in C-language) has been taken from Ref. [12]. An example of a PQS calculation process is shown in Fig. 3.

### Laboratory exercises

Our laboratory is equipped with 10 PCs with two seats per computer. DCTlab is implemented in MATLAB software to be used by students as a didactic tool. The minimum computational requirement specifications to execute DCTlab are the same as those required for the MATLAB software, since DCTlab was implemented in this software platform.

Laboratory exercises begin with the introductory module DCTlab Help which provides a theoretically solid introduction to still image compression using DCT. This is followed by four laboratory exercises: 1. Reconstruction Error Image, 2. Optimal Block Size, 3. Picture Quality Measures, 4. Frequency

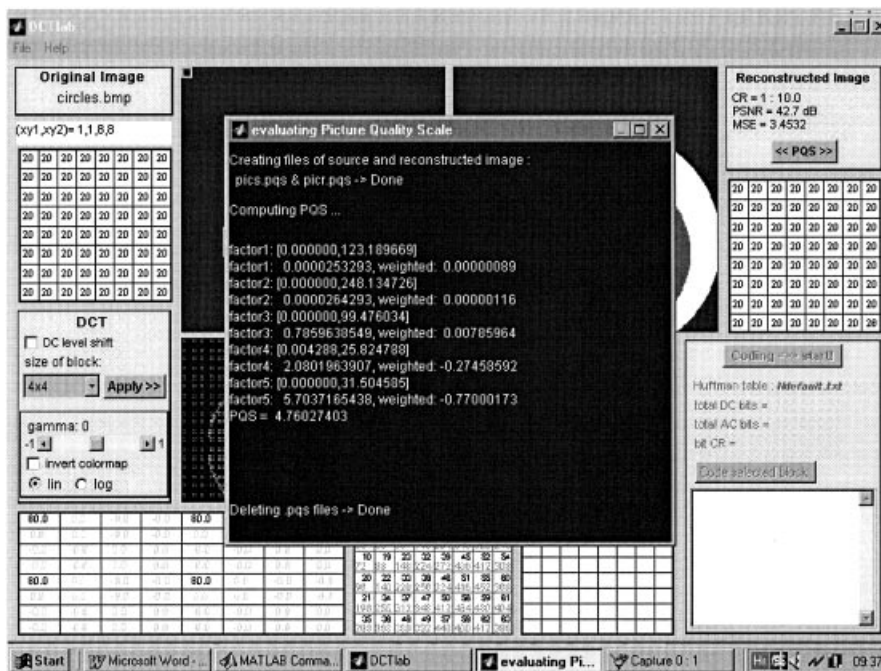


Fig. 3 An example of the PQS calculation process.

Analysis. The instructions and tasks are presented to students for each laboratory exercise. They are included as separate files that can be opened from the main window.

#### Exercise 1: reconstruction error image

The purpose of this exercise is to perform image compression using DCT and to calculate the difference between input and reconstructed image. Students compare the reconstruction error images for different input images and different block sizes. Usually, students have several minutes to explore on their own the role of changing DCTlab parameters. The example of the exploratory problem for this exercise is shown in Fig. 4.

An example of the results achieved for the exercise described is given in Fig. 5. Students find that the best result for the image 'Circles' is assigned for  $4 \times 4$  blocks and for image 'Barbara' for  $16 \times 16$  blocks. Hence, they can learn that results are highly dependent on image content and that a consequence of a relatively high compression ratio is noise and blocking artefacts in the images.

**EXERCISE 1: "Reconstruction Error Image"**

Activities:

1. "DCTlab" workspace provides comparison of input image and reconstructed image. Remember, there are two basic types of parameters for picture quality evaluation: objective (in our workspace MSE and PSNR) and subjective (in our workspace PQS).
2. Open the following test-image: "barbara.bmp".
3. For the test-image experiment with "size of block" parameter setting. Use following block sizes:  $4 \times 4$ ,  $8 \times 8$  and  $16 \times 16$ .
4. Take the DCT transform and display the results. Use the "Apply" operator.
5. For each "size of block" parameter, try to achieve CR=1:10 by changing the threshold value ("set threshold" operator). In this exercise quantization need not to be used.
6. Create the reconstruction error image and save it as a bmp-file.
7. Calculate the MSE and PQS values.
8. Include the input image, reconstruction error images, MSE and PQS values in your report.
9. Perform the same experiment (steps 3.-8.) with the test-image: "circles.bmp".
10. What is the optimal block size for each test-image? Discuss the difference between two test-images.
11. Present the results and answer the questions by writing a short but clear report in the Word editor. Generate pdf-file and submit the file directly to e-mail address: [sonja.grgic@fer.hr](mailto:sonja.grgic@fer.hr)

Fig. 4 An example of an exploratory problem for Exercise 1.

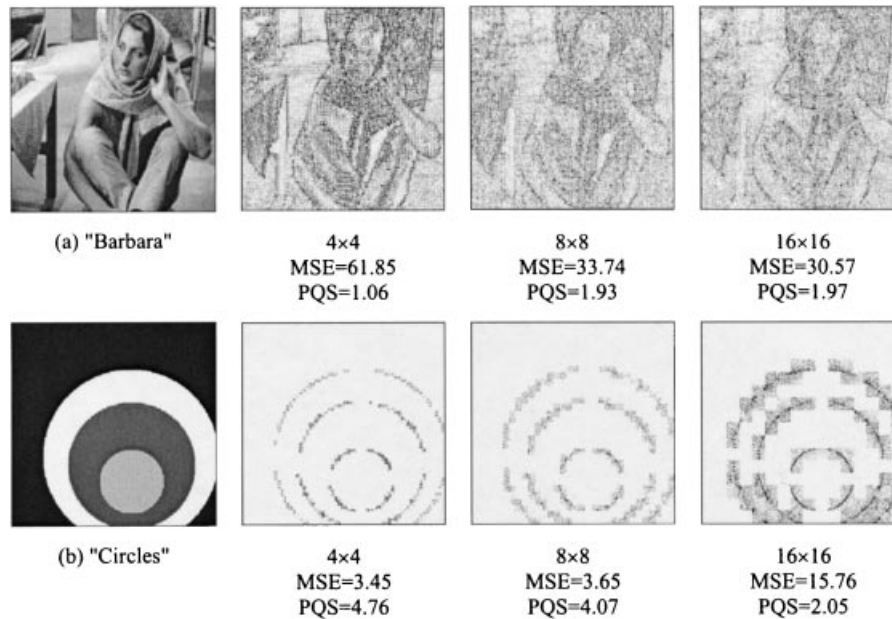


Fig. 5 Test images and reconstruction error images for different block sizes.  
(a) 'Barbara', (b) 'Circles'; CR = 10:1 in both cases.

#### Exercise 2: optimal block size

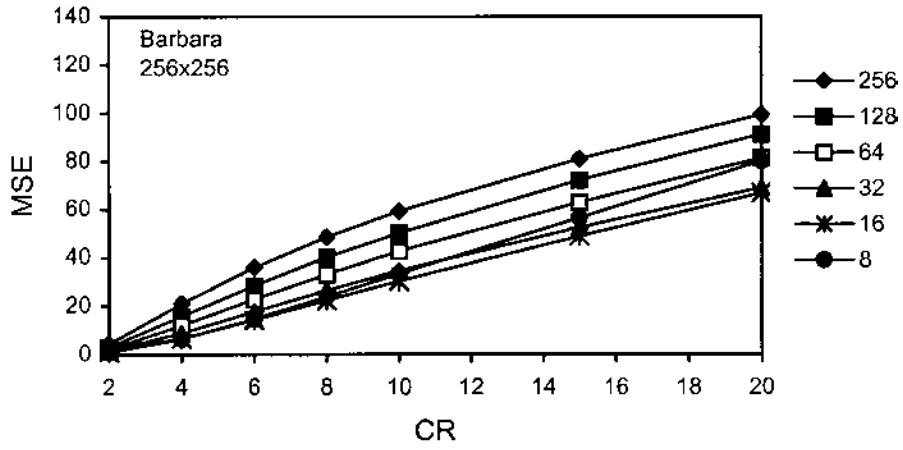
The purpose of this exercise is to gain an understanding of 2D DCT by applying it to images divided into blocks of different sizes. Two picture quality measures are used: MSE and PQS.

In this exercise, the input image is 'Barbara'. A total of 42 coded images need to be compared, representing a combination of seven different compression ratios (CR = 2, 4, 6, 8, 10, 15, 20) and six different block sizes ( $8 \times 8$ ,  $16 \times 16$ , ...,  $256 \times 256$ ). To compare the efficiency of DCT for different block sizes, students should draw a graph that shows CR outputs versus MSE and PQS. Figure 6 presents an example of the results. They can observe that  $16 \times 16$  and  $8 \times 8$  blocks work quite well for different compression ratios, which is an important fact for image and video compression standards. At higher compression ratios the  $16 \times 16$  block size shows better results according to both MSE and PQS. For compression ratios higher than 1:10 PQS values are below two for all block sizes. This means that subjective picture quality is very poor and unacceptable for most applications.

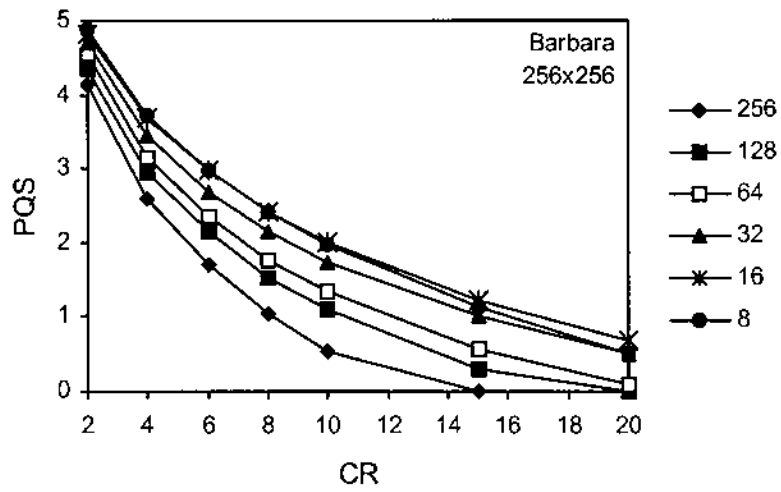
#### Exercise 3: picture quality measures

The purpose of this exercise is to compare objective and subjective picture quality measures.

Two sizes of the image 'Barbara' ( $256 \times 256$  and  $512 \times 512$ ) are used. Students should perform image compression with different compression ratios, which



(a)



(b)

Fig. 6 Image compression results with different block sizes. (a) MSE; (b) PQS.



are achieved by changing the threshold values. The 'size of block' parameter should be selected to be  $8 \times 8$  pixels. For both images similar results are achieved for MSE, but for PQS students can see large differences. The conclusions are derived by examining the obtained graphs. Figure 7 shows the example of MSE and PQS results. The  $512 \times 512$  image has noticeably higher

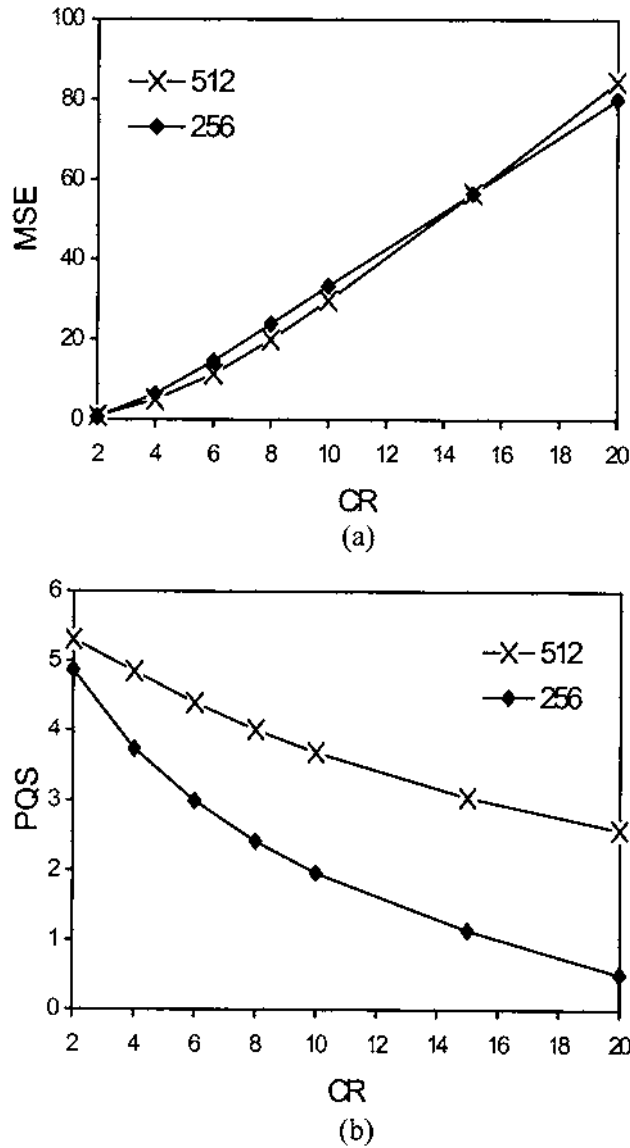


Fig. 7 Comparison of (a) MSE and (b) PQS results for the test image 'Barbara' using two different image formats ( $256 \times 256$  and  $512 \times 512$ ).

PQS values at all compression ratios. Hence, students can learn that input image resolution does not influence compression results if they consider only MSE. If they take PQS into consideration they can conclude that larger images will produce better visual image quality than smaller images at the same compression ratio.

#### Exercise 4: frequency analysis

The purpose of this exercise is to perform frequency analysis of images. Students can learn that the distribution of DCT coefficients is highly dependent on image content. It has consequences for DCT compression efficiency.

Frequency analysis calculations are carried out with the assumption that all coefficients with the same distance from the first DCT coefficient have the same absolute spatial frequency. Students study image frequency analysis characteristics using two geometric, Figs 8(a) and (b), and three photographic, Figs 8(c), (d) and (e), images. In this exercise, the whole image is treated as a single block. The first column in Fig. 8 presents input images, and the second column distributions of DCT coefficients. The distribution of DCT coefficients contains black dots, which represent DCT coefficients. Moving across the top row, horizontal spatial frequency increases. Moving down, vertical spatial frequency increases. The third column shows frequency analyses of the input images. Frequency is expressed as number of cycles per image size.

According to the results, students can see that the test image 'Horizontal Stripes' has a large number of higher harmonics. Test image 'Bird' has a 'continuous' spectrum as do most photographic images. Most of the energy is concentrated at low frequency components, so it can be efficiently compressed using DCT. Test image 'Baboon' has a large number of small details and therefore a larger number of high frequency components.

#### Conclusions

The educational software DCTlab was implemented in MATLAB software packages to be used in a digital television course as a didactic tool for still image compression. In this software it is possible to analyse the influence on image quality of each step in the DCT compression algorithm. Students can select input image, size of block in the DCT compression algorithm, quantization table and compression ratio. They can select one block in the input image and follow the changes in this block through all compression steps. Students can examine the compression results and can compare the visual quality of input and reconstructed image. DCTlab includes a part for the frequency analysis of input image and therefore students can explore the influence of image content on image quality. Using DCTlab students become fully active participants in the learning process and achieve a much deeper, practical and more permanent understanding of image processing concepts.

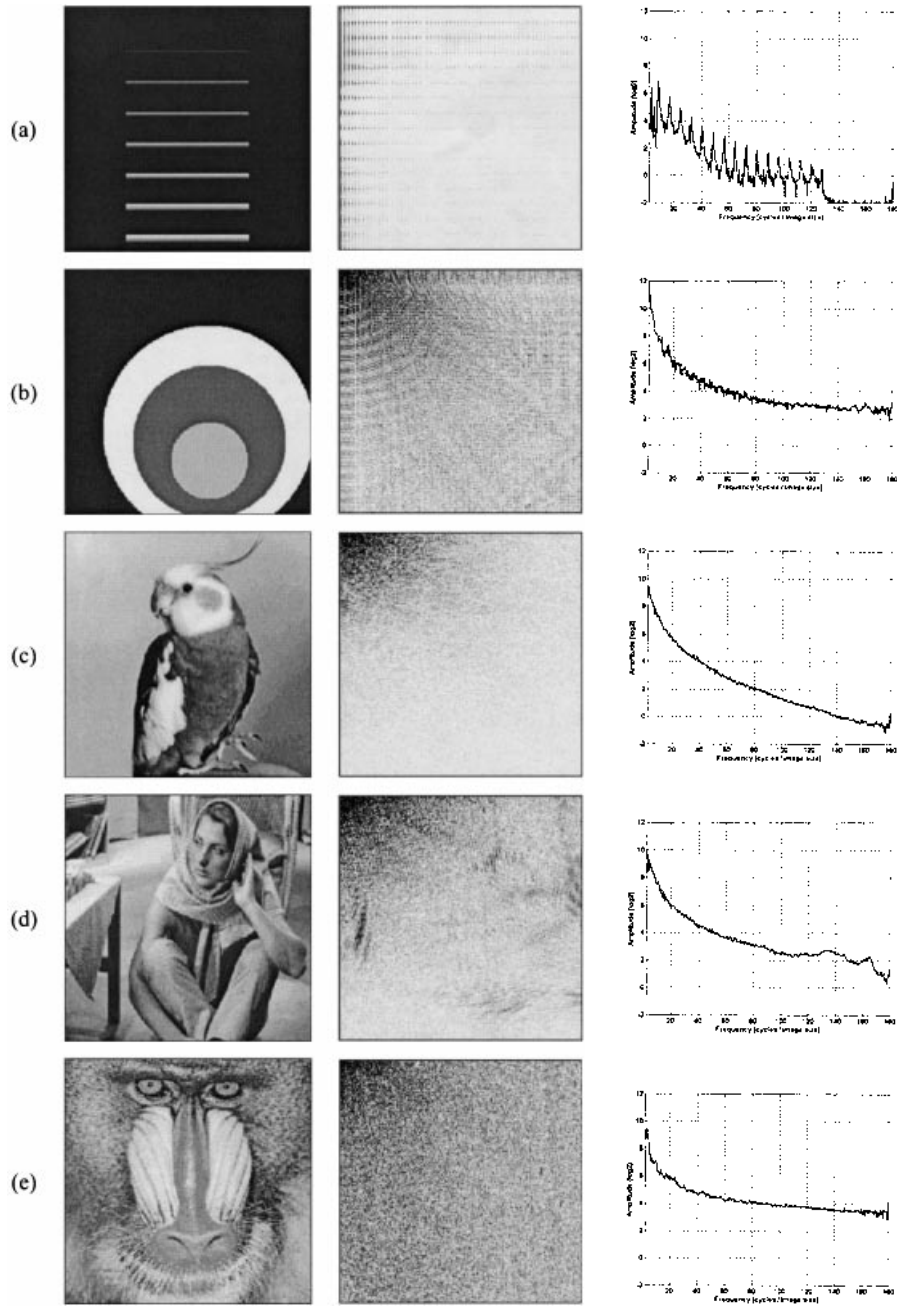


Fig. 8 Frequency analysis of the test images. (a) 'Horizontal Stripes'; (b) 'Circles'; (c) 'Bird'; (d) 'Barbara'; (e) 'Baboon'.

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