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ImAn - Educational Tool for Image Analysis

Nikola Sprljan, Sonja Grgic, and Mislav Grgic
University of Zagreb, Faculty of Electrical Engineering and Computing
Unska 3 / XII, HR-10000 Zagreb
CROATIA
E-mail: nikola.sprljan@fer.hr

Abstract--**In image compression system, statistical and subjective redundancies are removed to achieve bitrate reduction. Statistical and frequency characterisation of image is an important step for understanding how image compression systems work. Students specialising in image and video system engineering need to know why these characteristics are important in their field of interest and to understand the influence of these characteristics on image quality. Therefore, we have developed educational software, called ImAn - Image Analyser, that helps students to analyse statistical and frequency characteristics of images that will be presented in this paper.**

Index Terms--**Frequency Characteristics, Image Analysis, JPEG, JPEG2000, SPIHT, Statistical Characteristics.**

I. INTRODUCTION

IMAGE compression for both still and moving images is an extremely important area of investigation, with numerous applications to videoconferencing, interactive education, home entertainment, and potential applications to earth observation, medical imaging, digital libraries, and many other areas [1], [2]. Two compression methods are possible: lossy and lossless [3]. The lossless method enables the perfect reconstruction. It means that image quality before and after compression is unchanged. In lossless method, compression ratios are limited to small values. Lossy compression methods are based on removal of statistical and subjective redundancies in images and can achieve much higher compression ratios. By examining these redundancies, which can be analysed using statistical and frequency image properties, one can determine which type of compression is most suitable for particular image and particular application, and what quality can be expected [4].

Frequency properties give the best insight in subjective redundancy. Subjective redundancy is based on Human Visual System (HVS). Human perception of noise in image is a function of the spatial frequency. More noise can be tolerated at high spatial frequencies. These frequency components can be reduced or removed in a way that is least visible to the viewer. Due to the complexity of HVS, subjective redundancy is hard measurable, but it can be analysed using several statistic and frequency properties of image. The quality of compressed image is measured objectively mostly by Peak Signal-to-Noise Ratio (PSNR) [5]. The values of these quality measures usually can be brought to the relation with properties of the original image, so the information on those properties can be very useful in compression applications.

In this paper we present ImAn - Image Analyser, educational tool for image analysis that we developed. ImAn can help students to learn and understand how to perform statistical and frequency image analysis and what kind of characteristics is important for image compression applications. According to the results, students can study correlation between image content and image characteristics, and can analyse reconstructed images after compression in order to evaluate image compression system.

The paper is organised as follows. In section 2, statistical and frequency measures of images are defined. Section 3 contains ImAn program description. Section 4 illustrates results, which can be achieved using ImAn as an educational tool.

II. STATISTICAL AND FREQUENCY MEASURES OF IMAGES

For purpose of formality, we say that the image is represented by matrix **A**, whose elements *a(m,n)* represent intensity or luminance values at spatial coordinates *m,n* (*m* is the row, *n* is the column). Some basic statistical properties of image pixels are: $\overline{a}$ - mean value, <*a*> - range of values (min-max), χ_a^2 - mean square value, σ_a - standard deviation (variance), [3]. Probability density function - *pdf* [3], and zero-order entropy - H_0 (average number of bits required to represent one pixel) [6] indicate the type of image. Natural images have continuous *pdf* and high H_0, and the most of the artificial images have discrete *pdf* and low H_0. From these properties, the most appropriate quantization and entropy coding method can be determined.

First order entropy H_1 [6] is a measure of theoretical compression limit for lossless compression method that treats each pixel independently. The real limit for lossless compression is real entropy of image, which is practically incomputable, but higher order entropies can give close approximation. The relation for second order (conditional) entropy is $H_2 = - p(i,j) \cdot \log p(i,j)$, where $p(i,j)$ denotes the probability that a pixel has value i while its neighbouring pixel (in horizontal, vertical or diagonal direction) has value j [7]. It is an average number of bits needed for two pixels and for one pixel H_2 must be divided by two. We used second order entropy in one-pixel averaged form.

For better insight in dependencies between pixels in image, autocorrelation function can be used, and it can be evaluated separately for rows and columns. We use its normalised autocovariance form (here for rows):

$$\rho_R(k)=\frac{1}{M}\sum_{m=0}^{M-1}\frac{1}{\sigma_m^2}\left(\frac{1}{N-|k|}\sum_{n=0}^{N-|k|-1}\left(a(m,n)-\bar{a}_m\right)\cdot\left(a(m,n+|k|)-\bar{a}_m\right)\right) \quad (1)$$

where N denotes number of pixels in row, M number of rows, $\bar{a}_m$ and σ_m mean value and variance of pixels in m-th row. Similar equations can be written for columns.

Next step is frequency analysis of image. After 2D discrete Fourier transformation of image,

$$\theta(k,l)=\frac{1}{\sqrt{MN}}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}a(m,n)e^{-j\frac{2\pi km}{M}}e^{-j\frac{2\pi ln}{N}} \quad (2)$$

coefficients $\theta(k,l)$ lead to power spectral density $psd(k,l) = |\theta(k,l)|^2$, where k and l are spatial coordinates. For more appropriate investigation of image frequency spectrum, one-dimensional *psd* (1D-*psd*) is derived by computing the mean powers in 2D frequency bands of size $B(\Delta t)$. $B(\Delta t)$ is ring with centre in origin of frequency plane. It is determined in continuous domain by axis frequencies ω_1 and ω_2, which define spatial frequency $\omega=\sqrt{\omega_1^2+\omega_2^2}$. In discrete form it can be written as $t=\sqrt{k^2+l^2}$. One-dimensional *psd* is the mean power in all such rings:

$$\bar{P}(\Delta t=t_1-t_2)_{t_1,t_2}=\frac{1}{B(\Delta t)_{t_1 t_2}}\sum_{t_1\le t<t_2}psd(k,l) \quad (3)$$

The shape of *psd* can be described by a spectral flatness measure - *SFM* [3]:

$$SFM(\Theta)=\frac{\left[\prod_{k=0}^{M-1}\prod_{l=0}^{N-1}|\theta(k,l)|^2\right]^{\frac{1}{MN}}}{\frac{1}{MN}\sum_{k=0}^{M-1}\sum_{l=0}^{N-1}|\theta(k,l)|^2} \quad (4)$$

Totally flat spectrum has *SFM* of 1 and is related to completely unpredictable image, while lower *SFM* indicate more predictable image. More predictable images are easier for compression system to handle and for these images better image quality will be produced.

One additional measure is the spatial frequency - *sf* [8], which simply can be described as a mean difference between neighbouring pixels. This definition of frequency in the spatial domain indicates the overall activity in an image. *sf* is defined as:

$$sf=\sqrt{R^2+C^2},$$
$$R=\sqrt{\frac{1}{MN}\sum_{m=1}^{M}\sum_{n=2}^{N}\left(a_{m,n}-a_{m,n-1}\right)^2}, \quad (5)$$
$$C=\sqrt{\frac{1}{MN}\sum_{n=1}^{N}\sum_{n=2}^{M}\left(a_{m,n}-a_{m-1,n}\right)^2}$$

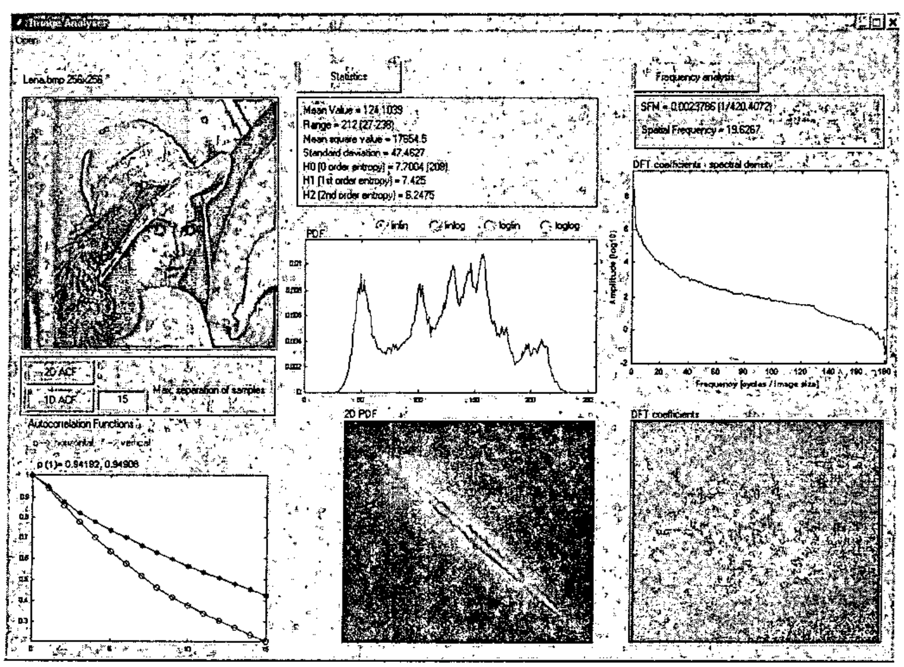


Fig. 1. ImAn window

TABLE I
STATISTICAL VALUES OF A FEW INPUT IMAGES

Input Image	$\bar{a}$	σ_a	$\rho_C(1)$	$\rho_R(1)$	H_0	H_1	H_2	SFM	sf
Noise	127.9	74.1	-0.004	-0.002	8.00	7.997	7.901	0.1423	147.77
Stripes	127.5	127.5	0.75	0.75	1.00	1.00	0.77	0	127.25
Text	214.0	72.9	0.62	0.46	4.00	1.72	1.61	0.0198	98.5
Baboon	129.4	42.1	0.59	0.67	7.76	7.35	7.02	0.0199	47.13
Lena	124.1	47.5	0.95	0.94	7.70	7.43	6.25	0.0024	19.63
Bird	125.1	45.8	0.98	0.99	7.65	7.22	5.51	0.0003	9.9

III. PROGRAM DESCRIPTION

Image Analyser - ImAn, is an educational tool for examining the statistical and frequency properties of images. Fig. 1 shows typical ImAn window with previously performed all evaluations of image properties (the used image is "Lena"). Students can load input image in the left ImAn frame. Below input image, autocorrelation functions for rows and columns can be displayed for selected number of samples. Statistical characteristics are displayed in the middle part of the window. They include few numerical measures, histogram (*pdf*) and 2D histogram (H_2) plots for chosen image. Student may choose linear or logarithmic display of histogram axes. Frequency analysis, located in the right part of window, can be done by applying DFT on input image. One-dimensional image frequency analysis and SFM value evaluated from DFT coefficients are also displayed.

IV. RESULTS

Table I presents statistical values that students can see using few artificial and natural images. Image "Noise" is array of random number with values from 0 to 255, and image "Stripes" is a basically two-dimensional square wave. The results in table show typical properties of natural images ("Baboon", "Lena", "Bird"). These images have high correlation between pixels, high entropy, relatively high difference between first and second order entropies (H_1-H_2), and low frequency characteristic. Artificial images ("Stripes", "Text") have low entropy and higher spectral characteristic. Image "Stripes" has *SFM* of zero and is totally predictable. Image "Noise" shows noise signal properties: no correlation, high entropy and high frequency characteristic.

To illustrate how ImAn can be used in image compression applications we performed JPEG [9], [10] image compression on three test images to the rate of 0.3 bpp. Visual image quality and PSNR results are presented in Fig. 2. These images are used as input images in ImAn.

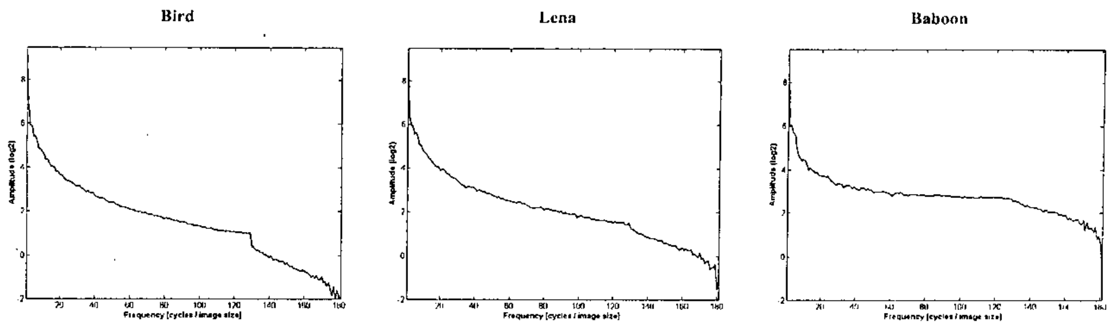
Fig. 3 presents 1D-*psd* for three input images before and after JPEG compression. These images have various spectral characteristics (note that the amplitude axis is logarithmic), Fig. 3(a). Image "Bird" has high values of autocorrelation functions and small values of sf and SFM (see Table I). Images "Lena" and "Baboon" have lower values of autocorrelation functions and higher values of sf and SFM than image "Bird". It means that image "Bird" contains more redundant data than images "Baboon" and "Lena". Consequently, image "Bird" is easier for compression system to handle. It is the reason why image "Bird" produces higher PSNR value than images "Baboon" and "Lena" for the same bitrate. Image "Baboon" has low predictability because of high values of sf and SFM. This image is hard for compression and it has lower quality than "Bird" and "Lena" for the same bitrate. Students can also see that the *psd*-shape is strongly related to the efficiency of compression method that uses subband coding and exploits the properties of HVS, Fig. 3(b), which is more sensitive to low frequency components.

(a) "Bird" - PSNR = 35.4 dB

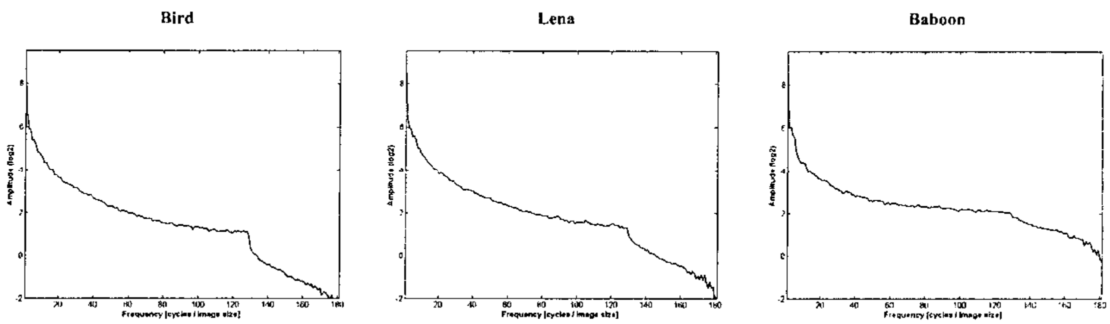
(b) "Lena" - PSNR = 27 dB

(c) "Baboon" - PSNR = 20.4 dB

Fig. 2. JPEG compressed images (0.3 bpp)



(a)

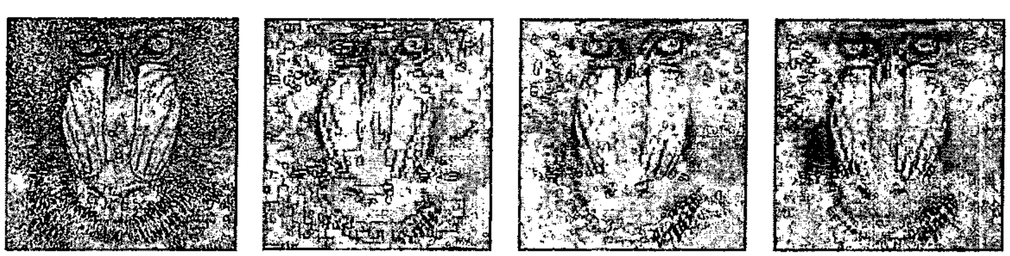


(b)

Fig. 3. Spectral characteristics (a) before JPEG compression (b) after JPEG compression for images Bird, Lena and Baboon

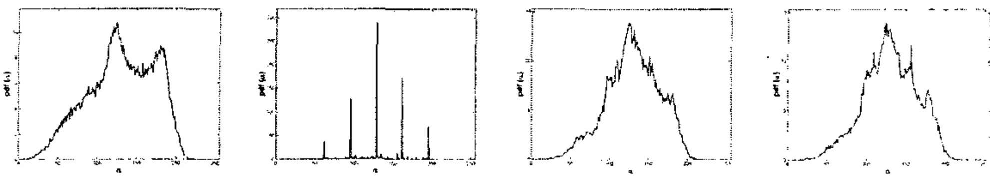
ImAn can also be used to compare efficiency of different compression methods. In this case, reconstructed image after compression is used as an input image loaded in ImAn. Fig. 4 presents result of 3 compression methods applied to image "Baboon": JPEG, SPIHT [11] and JPEG2000 [12]. Fig. 5 shows the histograms (*pdf*), Fig. 6 2D histograms, and Fig. 7 spectral densities achieved using ImAn.

It can be seen that 1D and 2D histograms of JPEG compressed image clearly show the impact of DC coefficients quantization, and resulting blockiness in image. Histograms of SPIHT and JPEG2000 compressed images show smoothing property of wavelet based image compression [13]. Spectral densities show low frequency filter behaviour of all three methods.



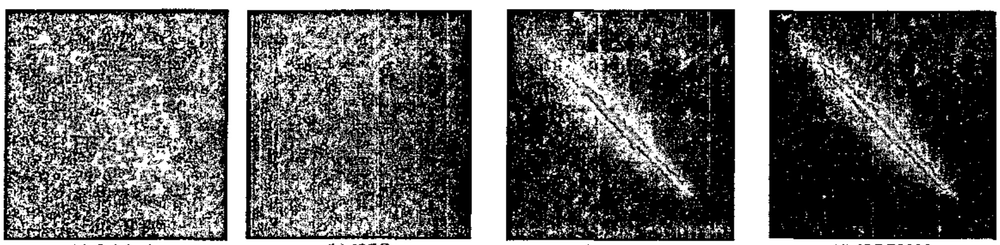
(a) Original (b) JPEG (c) SPIHT (d) JPEG2000

Fig. 4. (a) Original image "Baboon", and image "Baboon" compressed at 0.1 bpp using (b) JPEG, (c) SPIHT, (d) JPEG2000



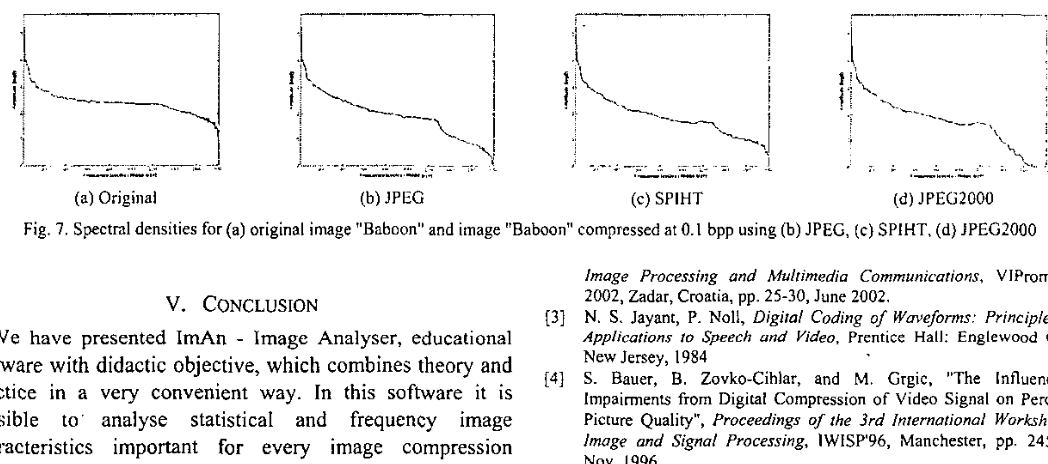
(a) Original (b) JPEG (c) SPIHT (d) JPEG2000

Fig. 5. 1D Histograms (*pdf*) for (a) original image "Baboon" and image "Baboon" compressed at 0.1 bpp using (b) JPEG, (c) SPIHT, (d) JPEG2000



(a) Original (b) JPEG (c) SPIHT (d) JPEG2000

Fig. 6. 2D histograms for (a) original image "Baboon" and image "Baboon" compressed at 0.1 bpp using (b) JPEG, (c) SPIHT, (d) JPEG2000



(a) Original (b) JPEG (c) SPIHT (d) JPEG2000

Fig. 7. Spectral densities for (a) original image "Baboon" and image "Baboon" compressed at 0.1 bpp using (b) JPEG, (c) SPIHT, (d) JPEG2000

V. CONCLUSION

We have presented ImAn - Image Analyser, educational software with didactic objective, which combines theory and practice in a very convenient way. In this software it is possible to analyse statistical and frequency image characteristics important for every image compression system. Students can explore the influence of image content to statistical and frequency image characteristics and to the image quality after compression. Students can compare the influence of different compression methods to image characteristics and consequently to the image quality. Using ImAn students become fully active participants in the learning process and achieve a much deeper, practical and more permanent understanding of the image processing concepts.

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