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HVS scheme for DICOM image compression: Design and comparative performance evaluation

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Abstract

Advanced digital imaging technology in medical domain demands efficient and effective DICOM image compression for progressive image transmission and picture archival. Here a compression system, which incorporates sensitivities of HVS coded with SPIHT quantization, is discussed. The weighting factors derived from luminance CSF are used to transform the wavelet subband coefficients to reflect characteristics of HVS in best possible manner. Mannos et al. and Daly HVS models have been used and results are compared. To evaluate the performance, Eskicioglu chart metric is considered. Experiment is done on both Monochrome and Color Dicom images of MRI, CT, OT, and CR, natural and benchmark images. Reconstructed image through our technique showed improvement in visual quality and Eskicioglu chart metric at same compression ratios. Also the Daly HVS model based compression shows better performance perceptually and quantitatively when compared to Mannos et el. model. Further "bior4.4" wavelet filter provides better results than "db9" filter for this compression system. Results give strong evidence that under common boundary conditions; our technique achieves competitive visual quality, compression ratio and coding/decoding time, when compared with jpeg2000 (kakadu).

Keywords: Image compression; SPIHT; DICOM; Human visual system (HVS); Contrast sensitivity function (CSF)

1. Introduction

Nowadays computers are playing a key role in understanding the static and dynamic conditions of human physiological systems. In this process various physical and mathematical principles combined with advanced computing technology generate images in non-invasive manner. Due to the limitations of storage space and transmission bandwidths, this visual image data has to be compressed into a low-bit rate stream by an efficient compression scheme [11,9]. In this process, the properties of human visual system (HVS) can be exploited in compressing these visual data. As human is the end-user of images and human visual system (HVS), stated as a sensor deployed with some optical artifacts [10,12], an exact bit-for-bit representation might not be needed; rather, the data can be coded in a non-invertible or lossy fashion. Many solutions have been proposed for embedding a model of the human visual system in compression algorithms. While initially developed perceptually tuned image coders were only concerned with the frequency domain behavior of the HVS [9], the recently developed coders exploit the spatial domain properties of HVS [15–17] in order to dynamically adjust the parameters of the compression algorithm according to the local properties of the image.

The discrete wavelet transform (DWT) based HVS image compression algorithms will not only approximately decorrelate the image and also provides good energy compaction, facilitating integration of HVS properties into the quantization. This band splitting properties similar to HVS, make it reasonable to be introduced in DICOM image compression [14]. The HVS model can be embedded either in the quantization stage [15,17] or in the bit allocation stage [16]. In the former approach a perceptually tuned step is computed for quantizing each DWT coefficient; the quantized coefficients are then entropy encoded and transmitted. In the latter approach, a fixed step is used for quantizing all of the DWT coefficient, but for each quantized coefficient a suitable number of bits are transmitted, according to its perceptual relevance.

Our algorithm incorporates sensitivities of HVS coded with SPIHT quantization [1]. Further, we do a comparison study

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between HVS models [2,3] (Mannos et al. and Daly models) and wavelet transform filters (Daubechies 9 and biorthogonal 4.4), where performance evaluation is done using Eskicioglu chart metric [8]. The paper is organized as follows: Section 2 gives some background information on DICOM, HVS models, CSF characteristics, transform based compression and Eskicioglu chart. Section 3 details about experimental results. Finally the discussion about the importance of present method is carried out in Section 4.

2. Materials and methods

2.1. DICOM

The digital imaging and communications in medicine (DICOM) standard was created by the national electrical manufacturers association (NEMA) to aid the distribution and viewing of medical images, such as CT scans, MRIs, and ultrasound. The DICOM format describes how to compose messages to send between imaging modalities and defines a set of operations for transmitting them across a network. These format messages combine images and header data to create a rich description, which encapsulate all of the information about a medical imaging procedure, including details about the patient, study, imaging modality, and image series in addition to the image frame stored in the file. DICOM image data can be compressed (encapsulated) to reduce the image size and to know whether DICOM file is compressed or not, transfer syntax unique identification is used.

2.2. HVS—imaging applications

A lot of work has been devoted for understanding the human visual system (HVS) and applying this knowledge to image processing applications. In image compression algorithms there has been a need of good metrics for image quality that incorporates properties of the HVS and of a good quantization matrix to provide better quality of compressed images with higher compression ratio.

2.3. Luminance and color

The first stage in the processing chain of HVS models concerns the transformation into an adequate perceptual color space, usually based on opponent colors. After this step, the image is represented by one achromatic and two chromatic channels carrying color difference information. This stage can also take care of the so-called luminance masking or lightness non-linearity, the non-linear perception of luminance by the HVS. Such a non-linearity is inherent to more sophisticated color spaces like CIE L*a*b*, but needs to be added to simple linear color spaces. In compression applications, it can be considered by setting the quantization precision of the transform coefficients. The overall sensitivity is described as a product of color sensitivity and contrast sensitivity. However, experiments have shown that for compression purposes the decorrelation of the color channels is more important than the color-pattern separability [10]. Therefore compression in a color space like Y, Cb, Cr is preferable.

2.4. Contrast and adaptation

The response of the HVS depends much less on the absolute luminance than on the relation of its local variations to the surrounding background, a property known as Weber–Fechner law [9]. Contrast is a measure of this relative variation, which is commonly used in vision models. While it is quite simple to define a contrast measure for elementary patterns, it is very difficult to model human contrast perception in complex images, because it varies with the local image content. Furthermore, the adaptation to a specific luminance level or color can influence the perceived contrast.

2.5. Contrast sensitivity function

One of the most important issues in HVS-modeling concerns the decreasing sensitivity for higher spatial frequencies. This phenomenon is parameterized by the contrast sensitivity function (CSF). The correct modeling of the CSF is especially difficult for color images. Typically, separability between color and pattern sensitivity is assumed, so that a separate CSF for each channel of the color space needs to be determined and implemented. The human contrast sensitivity also depends on the temporal frequency of the stimuli. Similar to the spatial CSF, the temporal CSF has a low-pass or slightly band-pass shape.

2.6. HVS models

Human visual system research offers mathematical models of how humans see the world. The contrast sensitivity function (CSF) describes humans' sensitivity to spatial frequencies. Two models of the CSF for luminance images, proposed by Daly and Mannos and Sakrison modulation transfer function, are given by.Daly HVS-model:

$$H(f) = \left(\frac{0.008}{f^{1.5}} + 1\right)^{-0.2} (1.42\sqrt{f} e^{-0.3\sqrt{f}}) \times (\sqrt{1 + 0.06 e^{0.3\sqrt{f}}}) \tag{1}$$

Mannos et al. HVS-model:

$$H(f) = 2.6\,(0.0192 + 0.114f)\exp(-(0.114f)^{1.1}) \tag{2}$$

where spatial frequency is $f = \sqrt{(f_x^2 + f_y^2)}$ with units of cycles/degree (f_x and f_y are the horizontal and vertical spatial frequencies). Fig. 1 depicts this CSF curve; it characterizes luminance sensitivity of the HVS as a function of normalized spatial frequency. The CSF is a bandpass filter: the HVS is most sensitive to normalized spatial frequencies between 0.025 and 0.125 and less sensitive to very low and very high frequencies. CSF curves exist for chrominance stimuli as well; however, unlike luminance stimuli, humans' sensitivity to chrominance stimuli is relatively uniform across spatial frequency.