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Coding algorithm for grayscale images based on Linear Prediction and dual mode quantization

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ABSTRACT

This paper proposes a novel algorithm for grayscale image compression based on dual mode quantization that is supported by improved linear prediction scheme. The idea of dual mode quantization comes from desire to exploit advantages of the both uniform and piecewise uniform quantizers, designed for discrete input samples. The algorithm performs quantizers with a low and medium number of quantization levels and with a fixed codeword length by using a pixel value prediction in preprocessing. The correlation of adjacent pixels is exploited as the main idea for improving the quality of image compression. The proposed prediction is linear and very simple for practical realization. An analysis of reconstructed image quality is presented considering several parameters and by comparing with few other methods – BTC, DPCM and with methods that use transformation coding. Experiments are done applying the proposed compression model to several standard grayscale test images. Special attention is given to determination of thresholds values that determine whether and which of the two offered quantizers to use. Moreover, method for determining the value of proposed quantizer's variance is explained. Obtained results show that proposed model ensures gain up to 6.14 [dB] compared to the BTC model that uses fixed piecewise uniform quantization for discrete input without a pixel value prediction as well as gain up to 5.89 [dB] compared to the DPCM model that applies dual predictor. The proposed algorithm could find application in current grayscale image compression and video standards.

1. Introduction

Digital image compression is an indispensable segment in modern telecommunication systems. Many widespread applications such as video telephony, video conferencing, processing and record keeping systems for transmission of television images of standard and high definition, multimedia systems, biomedicine, and other procedures use digital image compression to exploit resources in a more efficient way (Jayant & Noll, 1984).

This paper is focused on grayscale digital images that are mostly used in radiology applications. Nowadays, digital medical imaging very often incorporates smart systems that can identify automatically various structures (Santos et al., 2013). This way, diagnosing process can be significantly accelerated. However, there are several other active research areas that apply grayscale images. The simplicity of grayscale domain is commonly used in computer vision for moving object detection systems (Barcellos, Bouvie, Escouto, & Scharcanski, 2015; Karasulu & Korukoglu, 2012). Next, intelligent watermarking in biometric systems, that deals with grayscale texture masks, was discussed in Rabil, Tliba, Granger, and Sabourin (2013) whereas in Abdullah et al. (2014) is presented a novel approach for face recognition by using Symmetric Local Graph Structure (SLGS). Moreover, a new method of using empirical mode decomposition (EMD) technique for facial emotion recognition was discussed in Ali, Hariharan, Yaacob, and Adom (2015). Generally, grayscale images are obtained by measuring the intensity of light at each pixel in a single band of the electromagnetic spectrum (e.g. infrared, visible light, ultraviolet, etc.).

The basic idea behind digital data compression is to take a given representation of information and replace it with a different representation that takes up less space and from which the original information can later be recovered. Data compression let us store more information in the same space, to transfer it in less time or using narrower bandwidth. The aim of the image compression research is reducing the number of bits needed to represent an image by removing spectral and spatial redundancies as much as possible (Jayant & Noll, 1984; Salomon, 2007). The best image quality at a given bit-rate is the final objective of image

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compression. However, it is preferred that encoding algorithms have low level of complexity since that some video applications require real-time transmission, i.e. low end-to-end delay (latency). On the other hand, with the increase of compression ratio, processing time and image sensitivity to data losses and errors increase, too. Consequently, the required quality of the reconstructed image and video is application dependent.

In the most general classification, all compression algorithms can be classified into two groups: lossless compression algorithms and lossy compression algorithms (Jayant & Noll, 1984; Sayood, 2006). Lossless compression is referred as a compression method used in those cases where it is difficult or impossible to regain original image, or when original image contains some important information that could be damaged by the compression process. On the other hand, methods of lossy image compression are used when it can be tolerated to have some degree of information loss (video telephony, television, multimedia systems, etc.), or when it is easy to repeat recording.

BTC (*Block Truncation Coding*) is the method for image compression with losses proposed by Edward Delp and Robert Mitchell in 1979 (Delp & Mithcell, 1979). The input image is divided into non-overlapping blocks of size 4×4 before treatment. All blocks are processed independently by using two-level quantizer whose decision threshold and representational levels are adapted to local statistics of a block. After the first, basic version of BTC algorithm, which made the big impact in image compression evolvent, many improvements were published. Firstly, Lemma and Mitchell have proposed a new quantization method – AMBTC (*Absolute Moment Block Truncation Coding*) that has much lower complexity (Lema & Mitchell, 1984). Also, its practical implementation is much easier and cheaper. In Savic, Peric, and Dincic (2012a, 2012b) it was discussed piecewise uniform quantizer application in the modified BTC algorithm. Moreover, analysis is done applying forward adaptation to quantizer design.

The histogram of pixel values of an image can be modeled most successfully by using Gaussian mixtures (Yang & Wu, 2012). In this paper we use a model based on a difference between original pixel values and mean value of all pixels in a block that pixel belongs. This model follows Laplacian distribution. This way, we combine two well-known techniques, BTC and DPCM (*Differential pulse-code modulation*) – a widely used encoding technique in video standards (MPEG4). Furthermore, we introduce a dual mode quantization and improved linear prediction technique. Appropriate quantizer design is discussed as well.

Uniform quantization is the simplest but still popular quantization technique (Savic, Peric, & Dincic, 2010). Quantizer design is based on the choice of the number of levels and the determination of decision-making thresholds and representational levels. Uniform quantizer is very simple to realize – it is enough to memorize the maximum amplitude of the quantizer and quantization step, while all thresholds and representational levels could be calculated using these two parameters.

Piecewise uniform quantizer incorporates good characteristics of the both uniform and nonuniform quantization (Savic et al., 2012a, 2012b). Quantizer range is divided into k segments (usually $k = 2^n$, $n \in N$) and uniform quantization is applied in each one. Furthermore, the number of levels and the quantization step can be different for each segment. This way, piecewise uniform quantizer achieves performance close to the performance of nonuniform quantization but with the simplicity of design that is characteristic of uniform quantization.

In this paper we propose an algorithm that includes the both uniform and piecewise uniform quantization and uses a pixel value prediction as an improved method of grayscale image compression (Jayant & Noll, 1984; Peric, Petkovic, & Dincic, 2009; Savic, Peric, & Panic, 2011; Savic et al., 2012a, 2012b). Dynamic range of the source output is considerably larger than the dynamic range of the differences between samples. Moreover, it is shown in the literature that 99% of pixel-to-pixel differences lie in the range −31–31 (Sayood, 2006). These facts suggest us to propose an algorithm which is based on the prediction model by using differential encoding as an efficient approach to the lossless image compression (Choi, 2013).

Unlike traditional DPCM technique which is based on a fixed quantizer usage, we use a dual mode quantizer in this paper. After the linear prediction of pixels in a block, depending on the calculated variance, decision-making process of quantization is performed. A difference between predicted and the original pixel value is quantized by using fixed piecewise uniform quantizer or fixed uniform quantizer if the calculated variance is higher than the estimated threshold, while the selection process depends on the variance value. This way, proposed model can be applied in various systems for image processing, but its best application may be in video encoding systems since that DPCM technique is already used in those systems and proposed algorithm, including linear prediction, has low complexity. Although proposed algorithm provides high image quality, there are few existing techniques that provide higher compression ratio. These techniques have significantly higher complexity and they incorporate transformation coding, such as wavelet or curvelet (Li, Yang, & Jiao, 2010).

Experiments are done for three standard grayscale test images. As a measure of quality of the compressed image is commonly used *PSQNR* (peak signal-to-quantization-noise ratio), while the total average bit-rate is used as a measure of compression quality. Obtained results show that by using the proposed model for grayscale image compression, compared to the BTC model published in Savic et al. (2012a, 2012b), achieved gain is equal to 2.845 [dB] for $N = 32$. If $N = 16$, achieved gain is 6.140 [dB]. Moreover, the proposed model is compared to the improved DPCM model (Wu, 2014). This image compressive algorithm is based on variable block-size quadtree image segmentation applied to double predictor differential pulse code modulation (DP-DPCM). The comparison is done for standard grayscale test image Lena whereas observed measure is *SNR* (signal-to-noise ratio). This way, achieved gain is 5.89 [dB].

The paper is organized as follows. Firstly, in Section 2 is described system model and the proposed algorithm is shown in steps. Prediction scheme is considered for blocks of size $m \times m$. The proposed quantizer design is discussed considering the histogram of variances, in order to obtain optimal values of *PSQNR*. Next, obtained numerical results of applying the proposed model are analyzed in Section 2.1. Afterwards, in Section 2.2 are shown numerical results for classic BTC model and the comparison of the proposed compression algorithm to BTC model presented in Savic et al. (2012a, 2012b). Furthermore, appropriate comparison to DP-DPCM model presented in Wu (2014) is provided. Finally, explained image compression algorithm and achieved quantization performance are summed up in Section 3.

2. Coding algorithm and dual mode quantization

In this section, detailed algorithm of grayscale image compression will be presented. The algorithm exploits strengths of two traditional techniques – BTC and DPCM. Moreover, linear prediction of pixel values is applied in order to reduce the number of blocks that have to be quantized. In the end, the proposed algorithm combines strengths of the both uniform and piecewise uniform quantization by introducing a kind of dual mode quantization.

The algorithm works as follows. First of all, image of size $n \times n$ is divided into a set of non-overlapping blocks of size $m \times m$. The