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An efficient compression scheme based on adaptive thresholding in wavelet domain using particle swarm optimization

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A R T I C L E I N F O

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A B S T R A C T

Image compression is one of the most important research areas in the field of image processing due to its large number of applications such as aerial surveillance, reconnaissance, medicine and multimedia communication. Even when high data rates are available, image compression is necessary in order to reduce the transmission cost. For applications involving information security, a fast delivery also reduces the chances of compromise over a communication channel. In this paper, we explore the possibility of using one of the computational intelligence techniques, namely, Particle Swarm Optimization (PSO), for optimal thresholding in the 2-D discrete wavelet transform (DWT) of an image. To this end, a set of optimal thresholds is obtained using the PSO algorithm. Finally, a variable length coding scheme, such as arithmetic coding is used to encode the results. Finding an optimal threshold value for the wavelet coefficients is very crucial in reducing the source entropy and bit-rate reduction. The proposed method is tested using several standard images against other popular techniques and proved to be more efficient compared to other methods.

1. Introduction

Image compression is used to reduce the number of bits required for representation of an image and thus, reduces the required bit rate to efficiently transmit image signals over communication networks. This also reduces the memory required for various image storage related applications [1]. Many image compression techniques have been proposed in the last few decades, and the most widely adopted international image compression standard is JPEG [1], which was introduced in the late eighties. JPEG is based on the Discrete Cosine Transform (DCT) followed by the entropy coding scheme based on either Huffman or Binary Arithmetic Coding (BAC) [2]. Among the recently developed techniques, those based on wavelet transform have shown high compression ratios with low distortion.

Some of the first papers on wavelet image compression [3,4] present an excellent performance, and support the use of the wavelet transform in image compression. A number of researchers have described the same principles of wavelet image compression by looking from a system perspective, using filter banks and sub-band decomposition in the context of sub-band coding [2]. The seminal work on signal denoising via wavelet thresholding or shrinkage of Donoho and Johnstone [5,6] have shown that various wavelet thresholding schemes for denoising have near-optimal properties in the minimax sense and performs well in simulation studies of one-dimensional curve estimation [7]. However, by looking at the sub-band data,

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we find that the majority of the coefficients in the high frequency sub-bands are negligible. Usually, wavelet based compression algorithms use this important feature to achieve more compression with less distortion. On a seemingly unrelated front, lossy compression has been proposed for denoising in several works, which apply thresholding in the wavelet domain [8–11]. Moreover, there have been some efforts in using evolutionary algorithms such as Genetic Algorithm (GA) or Particle Swarm Optimization (PSO) to achieve a higher compression ratio. In [12], GA is applied to find the optimum code-book for Vector Quantization (VQ) compression methods. In [13], PSO is used to find a better quantization table for image compression.

In this paper, we explore the application of PSO to achieve more compression with minimum distortion via finding the optimum threshold values in different sub-bands. PSO is one of the techniques in the area of Computational and Collective Intelligence, which is proved to be very effective. Therefore, it serves a baseline algorithm for many applications. PSO is inspired by the social foraging behavior of some animals, such as the flocking behavior of birds and the schooling behavior of fish [14]. PSO shares many similarities with evolutionary computational techniques such as Genetic Algorithm (GA). The system is initialized with a population of random solutions and then, the system searches for optimum results in the solution space by updating generations. However, unlike GA, PSO does not involve operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current local best particles [15]. Particles in the swarm fly through an environment following the fitter members of the swarm, and generally adjust their movement towards historically good areas of the environment. The goal of the algorithm is to locate the optimum in a multi-dimensional hyper volume. This is achieved by assigning random initial positions to all particles in the space and small random initial velocities.

The rest of the paper consists of 3 sections. Section 2 describes the proposed method in detail, including all the components and techniques involved and how they work together to give optimal results. Section 3 describes various experiments performed on test images, the related results and its analysis. Finally, Section 4 concludes the paper discussing the implications of the current work and possible directions of future research in this area.

2. Proposed compression scheme using adaptive thresholding

The proposed compression scheme consists of three steps. First, a three level 2 Dimensional Discrete Wavelet Transform (2D-DWT) is applied in a hierarchical fashion to achieve 10 sub-bands. The energy of each of these sub-bands is different with respect to its level, as well as its position. Therefore, different thresholds are to be used for different sub-bands. In the second step, PSO is applied to determine the best threshold values for each sub-band. The final optimal threshold values are then used to remove the coefficients which are below thresholds. In this way, we have coefficients with noticeably less entropy, leading to a gain in compression. In the third and final step, a quantization followed by the Variable Length Coding (VLC) scheme is applied to reduce the bit rate required for data compression. In the following sub-sections, we explain each of these steps in more detail.

2.1. 2-D discrete wavelet transform

A wavelet transform (WT) decomposes a signal into its sub-band components of non-uniform bandwidth and can be realized by a filter bank [16]. Like the Fourier Transform, wavelet transform is applicable to both continuous as well as discrete signals. In addition, we can represent various functions in the form of its wavelet expansion. If the signal, scaling functions and wavelets are discrete in time, the wavelet series of the discrete-time signal is called DWT. DWT of a digital image consists of two series expansions: one corresponding to the approximation (low-pass filter), and the other related to the details of the image (high-pass filter) [17].

The *2D* DWT can be implemented with two separate applications of the one-dimensional decomposition in the horizontal and vertical directions as shown in Fig. 1(a). The low and high pass filters are applied to the image along rows and columns separately, and the filter outputs are sub-sampled by 2, resulting in three detailed sub-images: horizontal high-pass sub-image (HL), vertical high-pass sub-image (LH), and diagonal high-pass sub-image (HH); and one approximate low-pass sub-image (LL).

The decomposition process is then repeated on the low-pass sub-image LL to create the next level of the decomposition. In this way, the original image is decomposed into a hierarchy of three octave resolutions resulting in ten sub-images: LL3, and (HL_i, LH_i, HH_i), $i = 3, 2, 1$, where LL3 is the lowest resolution low-pass sub-image at layer 3 of the hierarchy. Fig. 1(b) shows a three-stage 2D wavelet transform of Lenna image.

2.2. Thresholding

Thresholding usually involves the conversion of signal values below a certain *threshold* to zero or equal to the threshold when values are higher than the *threshold*. In image processing, thresholding is commonly used for image segmentation. According to the type of image, different types of thresholding mechanisms are used. For example, in gray-scale images, it can be used to create a binary image (B/W image) [18] while in color images, different types of thresholding methods are used, including global and local thresholding. Global techniques are further classified as point-dependent and region-dependent techniques [18,19]. In our 2D-DWT decomposition, a unique threshold is determined for each sub-band, or a group of sub-bands based on their energy. All the coefficient values which are greater than a threshold value, are kept. For all other values which are less than the threshold, the coefficient values are changed to the threshold value. It should be noted that in our implementation the values below threshold are not being changed to zero,