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Minimizing the entropy of quantized post-interpolation residuals for hierarchical image compression

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Abstract

Adaptive parameterized interpolation for hierarchical compression of images is investigated. I propose an approach for optimizing the parameters of an adaptive interpolator, based on minimizing the estimation of the compressed data size (entropy of quantized post-interpolation residues). Based on the proposed approach, I develop an adaptive parameterized interpolator and propose a recursive procedure for estimating its parameters. I perform an experimental comparison of the proposed interpolator with averaging interpolators and an adaptive interpolator based on minimizing the sum of the interpolation errors. The advantage of the proposed interpolator in the size of compressed data is demonstrated at various maximum errors.

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Keywords: image compression; interpolation; quantization; compression ratio; entropy; maximum error

1. Introduction

Images have extremely large data sizes. The growth of data storage capacity does not solve this problem. In recent years, this problem is becoming increasingly significant because of the need to process multicomponent images, including multispectral and hyperspectral [1-3] images. In addition, some promising areas, such as remote sensing and shooting with atmospheric remote-piloted vehicles, impose additional, very specific requirements on the size and quality of the data. So we have to use effective, often specialized, methods of image compression [4].

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The number of approaches to image compression is very large [4-8]. The leader in terms of prevalence, of course, is the JPEG method [9], based on the cosine transform [10] and statistical coding [11] of the transformation result. The JPEG-2000 method [13] (based on the wavelet transform [12]) is less widespread. This method keeps the main advantages of the JPEG method and significantly outperforms it [14] by efficiency (compression ratio).

The listed methods, based on the special transformations, have the widest scope. But these methods have a number of irremovable drawbacks in specific areas related to the processing of specialized or unique data, which are subject to increased requirements by quality.

Fractal compression methods [15] have even greater potential for the compression ratio, but they have not been widely used because of their computational complexity and unnatural distortion of the images. It should also be emphasized that the general drawback of all the above-mentioned approaches to image compression is the difficulty (or even impossibility) of strict quality control, because we have to control the error in the space of the transformation coefficients, rather than in the original space.

Considering the above, in the situation of strictly quality control of compressed data and the restrictions on available resources, we need compression methods that do not use any spectral spaces. So these methods have to produce all the processing in the source brightness space. As an example of such methods, we consider differential [4, 6] methods of image compression, based on the prediction of image pixels from the previous (already processed) pixels and encoding of the prediction errors. The main advantage of these methods is simplicity and low computational complexity, the main disadvantage is low efficiency (low compression ratio).

The hierarchical [16-17] compression methods are the development of the differential compression methods. In such methods, the prediction of readings is performed in a hierarchical way: the pixels of more resampled image are interpolated on the basis of pixels of less resampled image. This processing procedure allows not only to significantly increase the compression ratio, but also to provide the possibility of rapid hierarchical access to compressed data, in which the decompression time of an image fragment is independent of scale. Hierarchical compression methods have other important advantages, such as the ability to control the speed of the formation of a compressed data stream, the possibility of increasing noise immunity, and the ability to control a maximum error. This is the reason for the relevance of the task of research and increasing the effectiveness of hierarchical methods of image compression.

One of the most important stages of hierarchical compression methods is the interpolator, in which the pixels of more resampled image are used for interpolation of the pixels of less resampled image. The most common interpolation algorithm in this situation consist in simple averaging [19-20] based on the nearest pixels of more resampled scale levels oa the image. This interpolation algorithm is very simple, but not effective, so an adaptive parameterized interpolator was proposed in [21], which uses various interpolating functions depending on the local features of the image. The parameters of this adaptive interpolator are calculated from minimization of the sum of the absolute values of interpolation errors (post-interpolation residuals). However, the adequacy of this criterion to the compression problem can not be confirmed, since a decrease in the interpolation error affects the size of compressed data only indirectly.

In this paper, we offer a more adequate approach to optimize the parameters of an adaptive interpolator, based on minimizing the size of compressed data itself (we use entropy [22] of post-interpolation residues as an estimation of compressed data the size). Based on the proposed approach, an algorithm for adaptive interpolation has been developed, and its comparison with other interpolation algorithms is performed.

2. Image compression based on hierarchical grid interpolation

Let's consider the hierarchical representation [16, 23-24] of an image $\mathbf{X}=\{x(m,n)\}$ as a set of scale levels $\mathbf{X}_l$:

$$\mathbf{X}=\bigcup_{l=0}^{L-1}\mathbf{X}_l\ ,\quad \mathbf{X}_{L-1}=\left\{x_{L-1}(m,n)\right\},\quad \mathbf{X}_l=\left\{x_l(m,n)\right\}\setminus\left\{x_{l+1}(m,n)\right\},\ l<L-1,$$

where L is the number of scale levels of image, $\{x_l(m,n)\}$ is the image resampled by step 2^l. Let the pixels be integer and non-negative.