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Wavelet-based medical image compression with adaptive prediction

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Abstract

A lossless wavelet-based image compression method with adaptive prediction is proposed. Firstly, we analyze the correlations between wavelet coefficients to identify a proper wavelet basis function, then predictor variables are statistically test to determine which relative wavelet coefficients should be included in the prediction model. At last, prediction differences are encoded by an adaptive arithmetic encoder. Instead of relying on a fixed number of predictors on fixed locations, we proposed the adaptive prediction approach to overcome the *multicollinearity* problem. The proposed innovative approach integrating correlation analysis for selecting wavelet basis function with predictor variable selection is fully achieving high accuracy of prediction. Experimental results show that the proposed approach indeed achieves a higher compression rate on CT, MRI and ultrasound images comparing with several state-of-the-art methods.

Keywords: Image compression; Medical image; Selection of predictor variables; Adaptive arithmetic coding; Multicollinearity problem

1. Introduction

Medical images are a special category of images in their characteristics and purposes. Medical images are generally acquired from special equipments, such as computed tomography (CT), magnetic resonance (MRI), ultrasound (US), X-ray diffraction, electrocardiogram (ECG), and positron emission tomography (PET). In practice, the compression of medical images must be lossless because a minor loss may result in a serious consequence. We here accordingly focus on the development of an adaptive prediction scheme for lossless medical image compression.

One of the key techniques for efficient compression is prediction. The function of a prediction is to infer the current data by means of the previously known data. The predicted value should approximate the original value; in other words, the differences between the original data and the predicted values are expectedly minimal. In general, the compression efficiency is highly related to the accuracy of the prediction scheme [1]; thus a high accuracy prediction scheme is pursued. Many advanced image compression techniques have been developed in response to the increasing demands for medical images. JPEG2000 [2–4] combines embedded block coding with optimized truncation (EBCOT) technique with lifting integer wavelet transform to offer plenty of advanced features. It is able to provide a high performance lossless compression that is superior to JPEG standard at low bit rate. Wu and Memon [5,6] proposed the context-based adaptive lossless image codec (CALIC) approach utilizing *enclosing* (360°) *modeling contexts* to obtain the distribution of the encoded symbols and the prediction scheme. Moreover, an interband version of CALIC [7] which incorporates interband prediction technique into the original CALIC was proposed for multispectral and remotely sensed images. Przelaskowski [8] proposed the scanning statistical modeling (SSM) method providing a lot of experimental evidences in a series of processes: raster scan, 5/11 filter, and quincunx decomposition, for medical image compression. For lower-quality *ultrasound* images, SSM can achieve a high compression rate. Buccigrossi and Simoncelli [9] proposed the lossy embedded predictive wavelet image coder (EPWIC) adopting conditional probabilities calculated from their proposed statistical model for prediction. Although the experimental results show that the conditional probability model appears to be incompatible with CT images, its statistical analysis is still helpful understanding image properties to enhance the compression capability.

To achieve a higher compression rate for lossless-compressed medical images, we propose a wavelet-based compression scheme incorporated with an adaptive prediction (WCAP). At first, we initiate a correlation analysis of wavelet coefficients to identify a proper basis function for wavelet decomposition,

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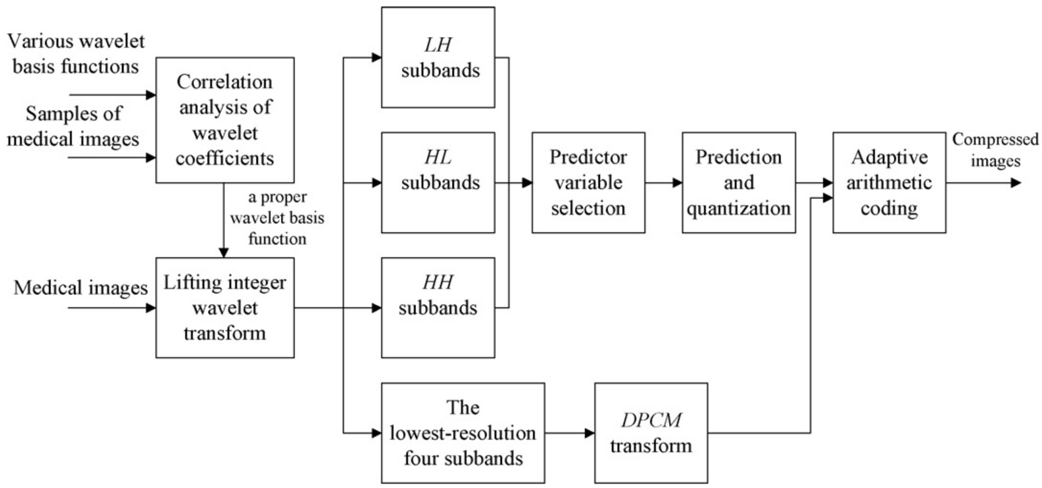

Fig. 1. The block diagram of the proposed WCAP scheme.

where wavelet coefficients are regarded as the predictor (independent) and response (dependent) variables of a prediction equation. Then we launch the selection of predictor variables based on a statistic test to determine which predictor variables should be included in the prediction equation. The generated prediction equations are then applied to predict most wavelet coefficients except the lowest-resolution coefficients. Finally, an *adaptive arithmetic encoder* is adopted to encode the differences between the original and corresponding predicted coefficients.

The proposed WCAP method consists of five stages: correlation analysis of wavelet coefficients, lifting integer wavelet transform, predictor variable selection, prediction and quantization, and adaptive arithmetic coding, as shown in Fig. 1 and briefly described as follows:

i. Analyze the correlations between wavelet coefficients to identify a proper wavelet basis function and the higher-correlation coefficients.
ii. Decompose a medical image using a lifting integer wavelet transform with the identified basis function.
iii. Construct adequate prediction equations to describe the relationship of wavelet coefficients in LH, HL, and HH subbands, respectively.
iv. Apply the prediction equations to compute the differences between the original and corresponding predicted values.
v. Use adaptive arithmetic coding [10,11] to code the differences.

The remaining sections of this paper are organized as follows. Section 2 describes the correlation analysis of wavelet coefficients for identifying a proper wavelet basis function and higher-correlation coefficients. The selection of predictor variables and prediction are presented in Section 3. Experiments are reported in Section 4. Conclusions are given in Section 5.

2. The correlation analysis of wavelet coefficients

The wavelet transform records the differences between neighboring signals in several different scales [12]. The wavelet coefficients have the locality, multiresolution, compression, clustering, and persistence properties [13] and therefore are suitable for signal/image analysis. Lifting integer wavelet decomposition has further properties for signal/image analysis: (i) it transforms integers to integers and allows perfect reconstruction of the original data; (ii) it is capable of accomplishing fast in-place computation. The persistence and clustering properties mean that a large/small wavelet coefficient tends to have large/small values in its neighbors and across scales. Hence, wavelet transform simultaneously take advantages of the interscale and intrascale dependencies among wavelet coefficients.

To select a proper wavelet basis function, the high intrascale and interscale dependencies are pursued. We take wavelet coefficients as random variables and use correlation of coefficients to evaluate the dependencies. The correlation of wavelet coefficients x and y is given as

$$r_{xy} = \frac{\mathrm{SS}_{xy}}{\sqrt{\mathrm{SS}_{xx}}\sqrt{\mathrm{SS}_{yy}}}, \quad (1)$$

where SS_{ij} is the covariance of coefficients i and j, and SS_{ii} is the variance of coefficient i,

$$\mathrm{SS}_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{n},$$

$$\mathrm{SS}_{xx} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n},$$

and

$$\mathrm{SS}_{yy} = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}.$$

We consider several wavelet basis functions. For each basis function, we examine all coefficients in the *parent*, *aunt*, and *current* subbands of every processing coefficient to find the higher-correlation coefficients as illustrated in Fig. 2. The higher-correlation coefficients are firstly used to determine which wavelet basis function is the best for the prediction and secondly used in the following stage to select the final predictor variables.