Lossless 4D Medical Images Compression with Motion Compensation and Lifting Wavelet Transform

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Abstract—**The lossless compression of 4D medical images is largely used for reduce the important size of this images and permit to reconstruct an identical image to the original image for diagnostic purposes. In this paper, we present a lossless compression technique of 4D medical images based on motion compensation and temporal filtering. The technique consists to apply 2D integer wavelet transform followed motion compensation or lifting wavelet order to eliminate efficiently the spatial and temporal redundancies between the 2D slices components a 4D image. The wavelet coefficients obtained are coded with SPIHT3D algorithm. Experimental results show that proposed technique can give better results compared to the classic technique such as SPIHT3D in compression rate.**

Index Terms—**4D medical images, SPIHT3D, lifting transform, motion compensation**

I. Introduction

The medical images are in continuous development due to the advancement of computer and visualization technologies by giving a more precise representation of the different parts of the human body. However more the image is precise more the quantity of the data generated is big. The medical images as magnetic resonance (IRM), computerized tomography (CT) and dynamics echocardiography 3D is more used, because they are considered among the most effective techniques in medical imagery, but they produce the voluminous data, from where the necessity of their compression for ends of storage and/or transport via telecommunication networks.

A number of approaches have been developed for the compression of the 4D medical images, the most intuitive technique is to use the techniques of the 2D images and 3D in the case 4D we can mention techniques without motion compensation [1], [2]. These use the wavelet transform for decorrelate the data in different directions (special, temporal).

Other approaches use the techniques of video compression, they can be represented by two groups the predictive approaches based on motion compensation [3]-[5] and the wavelet approaches based on motion-compensated temporal filtering (MCTF) [6] to exploit efficiently the existing spatial and temporal redundancies between the volumetric images constitute the 4D sequence.

Hence the motion-compensated temporal filtering (MCTF) is largely used in video compression scheme for its ability to produce a scalable flux. The first works introduced the Haar filter for motion-compensated temporal filtering [7], [8]. In Ref. [9] two motion-compensated lifting schemes are presented the Haar lifting filter and the 5/3 lifting filter, lifting enables a compression scheme without loss. Also in [10] motion-compensated lifting scheme is used by applying the truncated 5/3 lifting filter where the low-pass filtered is omitted which allowed improving the compression ratio by reducing motion costs.

In this paper, we implement motion compensation or a temporal wavelet transform in the temporal direction to effectively eliminate redundancies inter-slices in 4D medical image. The proposed technique applies the wavelet transform on the axes of the slice: horizontal and vertical followed by motion compensation (forward or backward) or the truncated 5/3 lifting filter in the temporal direction, the choice between motion compensation in forward or backward direction and the truncated 5/3 lifting filter is determined by the minimum prediction error obtained. The result subbands are coded with SPIHT3D. We compare the results with motion compensation using truncated 5/3 lifting filter scheme and SPIHT3D.

The rest of the paper is organized as follows. The section 2 exposes our approach of compression of the 4D medical images. In the section 3 the compression results

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are reported and discussed. Finally a conclusion is presented in the section 4.

II. Proposed Scheme

A. *Reorganization of Slices*

The 4D medical image is a succession of volumes in time, and each volume is composed by a set of slices.

The first step of our scheme is the reorganization of the slices, it consists to representing 4D image by *N* Group of Slices (GOS) and each GOS is composed by *M* 2D slices. For example if 4D image is composed by 4 volumes then the first GOS starts with four first slices of the four volumes, followed by four second slices of the four volumes until achieve *M* slices of the first GOS and thus all other GOS will be achieved by continuing to browse the rest of the 4D image (Fig. 1).

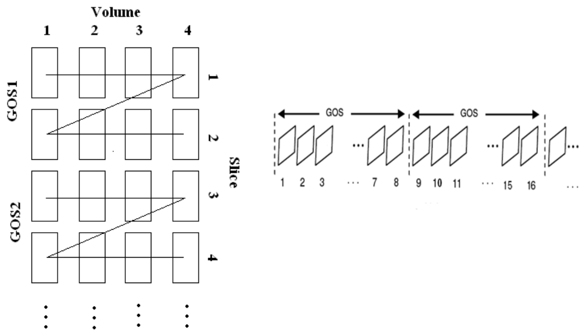

Figure 1. Reorganization of 2D slices in GOS with M=8 slices.

B. *2D Integer Wavelet Transform*

In this step each slice in the GOS is decomposed by using 2D wavelet transform with lifting scheme. The wavelets transform produce a hierarchical representation by applying successive levels of decomposition along horizontal and vertical axes of the image, this representation permits to create a low subband (approximation of image) and high subbands (details).

Fig. 2 represents the obtained subbands for each transformed slice of a GOS composed by 8 slices, after achieving 2D integer wavelet transform in spatial direction (horizontal and vertical) for two decomposition levels.

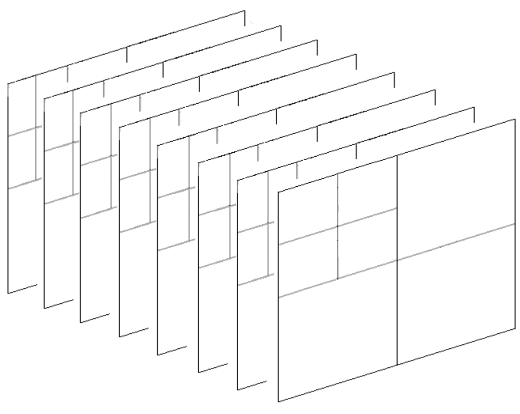

Figure 2. 2D integer wavelet transform with 8 slices and two decomposition levels

Where each transformed slice is constituted by a low subband (at the top left) and high subbands.

The scheme lifting permits to obtain integer coefficients of wavelets [11]. This functionality is essential to be able to achieve lossless compression technique. It consists in two steps: the high pass called predict step and the low pass called update step.

In our method we use a 2D integer wavelet transform achieved by the scheme lifting for three decomposition levels.

C. *Motion Compensation / Lifting Wavelet Transform*

In the motion compensated lifting scheme [9], [10] the motion compensation and the wavelet transform perform in the same time. While the proposed scheme applies either the motion compensation (forward or backward) or truncated 5/3 lifting filter where only prediction step lifting is perform.

The prediction step lifting between slices A, B and C by using truncated motion compensated 5/3 transform can be formulated as follows:

$$H\left[m,n\right] = B[m,n] - \left\lfloor 0.5\times\left(A\left[m-d_{1m},n-d_{1n}\right]+C\left[m-d_{2m},n-d_{2n}\right]\right)\right\rfloor \tag{1}$$

where A and C: reference slices.
B: predicted slice.
(d_{1m}, d_{1n}): motion vector which represents the displacement from B to a position in A.
(d_{2m}, d_{2n}): motion vector which represents the displacement from B to a position in C.
$\lfloor . \rfloor$: corresponds to round operator.
H: high-pass slice or residual slice because it represents prediction error obtained between predicted slice B and reference slices A and C.

Fig. 3 show 2 levels truncated motion compensated 5/3 transform for GOS with 8 slices the results are the reference slices (1, 5), the residual slices (P1, P2, P3, P4, P5 and P6) and 2 motion fields for each the predicted slice. Thus the slice (9) is used as the first slice in the next GOS.

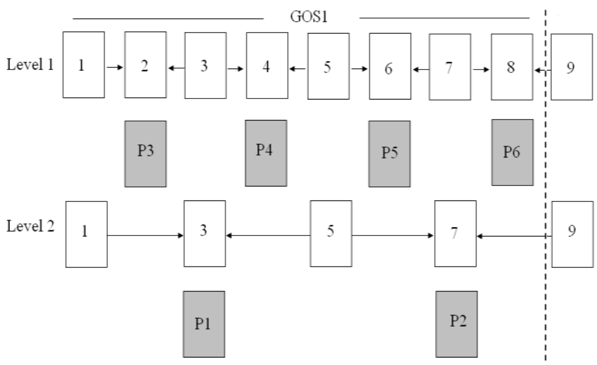

Figure 3. Truncated motion compensated 5/3 transform with 8 slices per GOS

In the proposed technique, three prediction errors are calculated:

The prediction step lifting between slices A, B and C by using truncated 5/3 transform can be formulated as follows:

$$E_1\left[m,n\right] = B[m,n] - \left\lfloor 0.5\times\left(A[m,n]+C[m,n]\right)\right\rfloor \quad (2)$$

The two prediction errors obtained by motion compensation in the forward and backward directions:

$$E_2\left[m,n\right] = B[m,n] - A[m-d_{1m}, n-d_{1n}] \quad (3)$$

$$E_3\left[m,n\right] = B[m,n] - C[m-d_{2m}, n-d_{2n}] \quad (4)$$

Among the three errors the minimum error is chosen well as the prediction method for pixel (*m*, *n*) of the predicted slice B.

So for 2 levels of decomposition we obtain using the proposed method (Fig. 4) for GOS with 8 slices: the reference slices (1, 5), the residual slices (P1, P2, P3, P4, P5 and P6), one motion field (forward or backward) and the corresponding etiquette to indicate which prediction methods are used for each predicted slice. The slice (9) is used as the first slice in the next GOS.

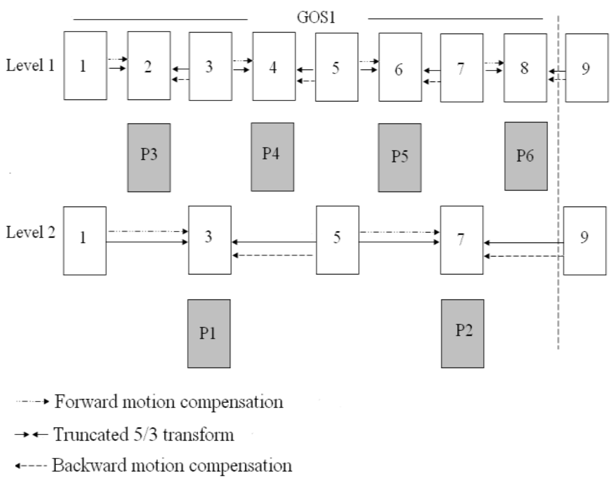

Figure 4. The proposed scheme with 8 slices per GOS

In our scheme after applying the 2D integer wavelet transform on all slices constituting the GOS, the obtained subbands are either compensated in motion (forward or backward) or filtered using truncated 5/3 lifting filter to eliminate redundancies inter subbands effectively.

We adopt block motion compensation model with simple full search method to find the most similar blocks between reference and predicted slices with integer pixel accuracy. However more pixel accuracy can be used in the proposed scheme.

To calculate the motion vectors, a predicted slice is divided into blocks with size of 16*16 pixels, each block must be compared to all of the blocks of the reference slice in the search windows for find the most similar block which provides the minimal Mean Absolute Difference with predicted block. The difference between the location of predicted block and the location of the most similar block is the motion vector.

D. *SPIHT3D*

Between different subbands of wavelet transform appear the dependences, which can be to exploit in compression. This property is the basis of the Set Partitioning in Hierarchical Trees (SPIHT) algorithm. The algorithm SPIHT used for the compression of the 2D images exploits the relationships existing in subbands between two consecutive resolution levels (parent-child relationship) and between distant resolution levels (across decomposition levels). By the algorithm SPIHT the vast zones are isolated of non significant coefficients, which permits to obtain good performances in the compression. The SPIHT algorithm has been spread to the case 3D for the video [12] and for the compression of volumetric images by using a 3D wavelet transform. The principles of basis of SPIHT 3D are identical to it version 2D (exploits the inter dependences in three dimensions).

In our approach we use SPIHT3D for coding the wavelet coefficients obtained after motion compensation or lifting transform in the temporal direction.

III. Tests and Results

We tested the proposed compression method with 4D medical images CT (Computed Tomography) of heart [13].

The 4D image CT is composed by 10 volumes, every volume contains 141 slices, and the size of every slice is 512×512 coded on 16bits per pixel. We present the experimental results obtained with the proposed approach and compare its lossless performance against using the truncated motion compensated 5/3 transform (TMC 5/3) and SPIHT3D.

In spatial direction (horizontal and vertical) 2D integer wavelet transform is applied, we test 5/3 and 9/7 filters with three decomposition levels for all three implementations with 16 slices per GOS and each GOS is reorganized as show in Fig. 1.

After the spatial wavelet transform in TMC 5/3, the obtained 16 transformed slices are decomposed in temporal direction with truncated motion compensated 5/3 transform (Fig. 3). The result slices (reference and predicted slices) are coded with SPIHT3D and the motion vectors are entropy coded. In our approach, the obtained 16 transformed slices are decomposed in temporal direction with the motion compensation (forward or backward) or truncated 5/3 lifting filter (Fig. 4). The result slices are coded with SPIHT3D, the motion vectors and the etiquettes are entropy coded.

In the case of SPIHT3D, each GOS is compressed independently by using 3D integer wavelet transform, thus after the spatial wavelet transform the obtained 16 transformed slices are decomposed by 1D integer wavelet transform in temporal direction. The result slices are coded with SPIHT3D.

We tested the compression performance of different methods by using two first volumes of the 4D image, the Table I summarizes the results of the lossless compression which are compared by compression rate in bit per pixel (bpp).

TABLE I. COMPRESSION RATE (BPP) BY TESTING 5/3 AND 9/7 FILTERS.

Filter	SPIHT3D	TMC 5/3	Proposed method
Filter 5/3	5.19	5.23	**5.14**
Filter 9/7	5.23	5.25	**5.16**

In Table I we show that our method performs better than TMC 5/3 and SPIHT3D in compression rate with 2 first volumes of the 4D image whatever the filter used in spatial direction, as we note that the 5/3 filter give the best compression rate than 9/7 filter.

In Table II we present the results obtained by using the 5/3 filter in spatial direction. We used different size of the 4D medical image for example: the first data called 2 volumes this means the two first volumes of 4D medical image are tested, the last data 6 volumes this means the six first volumes of 4D medical image are tested. The different sizes of image permit to construct different GOS over the temporal axes.

TABLE II. COMPRESSION RATE (BPP) BY USING DIFFERENT SIZE OF 4D IMAGE TO CONSTRUCT GOS.

Size of 4d medical image	SPIHT3D	TMC 5/3	Proposed method
2 Volumes	5.19	5.23	**5.14**
4 Volumes	5.07	5.10	**5.02**
6 Volumes	5.06	5.05	**4.99**

Our method performs better than TMC 5/3 and SPIHT3D in compression rate with different image sizes. The obtained results for data with 6 volumes represent the best compression rates whatever the method used, its slices are very similar allowing a good decorrelation in temporal axis, while the number of slices located in the same position in z axis at different times is numerous we obtain a better compression rate.

IV. CONCLUSION

We have described a technique of compression of 4D medical images, this technique applies 2D integer wavelet transform followed eider motion compensation or lifting transform. The result coefficients of wavelet are coded with algorithm SPIHT3D. Experimental results show that the proposed technique can give better results in lossless compression compared to the classic techniques.

The future work may consist to incorporate region of interest coding into our image compression technique.

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