Coronary Angiogram Video Compression

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Abstract - The use of digitized information is rapidly gaining acceptance in radiological applications. Image compression plays an important role in the archiving and transmission of different digital diagnostic modalities. Currently block DCT based compression schemes (i.e. JPEG, MPEG) are usually used for telephone conferencing, cable video transmission and other non-medical applications. This scheme is not suitable for medical video sequences (like angiograms) because of block artifacts resulting from the block based DCT coefficient quantization. The image quality degrades severely with consecutive frame processing due to accumulation of errors across frames. We have developed a compression scheme for angiogram video sequence coding based on full frame wavelet coding. This full frame design exploits the local characteristics of the compensated difference signals (via block matching) and achieves a higher coding gain. At the same compression ratio, the proposed technique outperforms the block DCT method in image quality preservation. Our algorithm not only achieves a higher compression ratio but also maintains high fidelity for the reconstructed image which could be used in the PACS system and telediagnosis environment.

I. INTRODUCTION

Among medical imaging modalities, angiograms constitute one of the most important data sources for cardiovascular radiology. Conventional angiograms are stored on film (hard copy) and take about 30 minutes to develop after each procedure. With the assistance of digital facilities in a hospital, a digital video record of the angiogram can also be generated during the procedure and saved to disk. This enables clinicians to quickly review the data and perform a diagnosis without waiting for the film development. Digital image data has the further advantage of being suitable for image processing functions such as windowing, leveling, zooming, and edge detection and allows multi-user access and easy data retrieval, duplication and distribution. Applications that may take advantage of these features for communications include Picture Archiving and Communications Systems (PACS), Radiology Information Systems (RIS), and Hospital Information Systems (HIS). A typical digital angiogram study is recorded at a rate of 30 frames/sec at a resolution of 512 by 512 picture elements (pixels) or 1024 by 1024 pixels, with 8 bits gray-level intensity for each pixel. Recording processes often last five to seven minutes during the study, resulting in more than 2 gigabytes of digital information. These large data volumes can quickly fill available storage media and are cumbersome to transfer between sites over communications links on which data rates are limited to several megabits/sec or below. The storage and transmission problems that arise due to the large volume of digital angiograms can be significantly mitigated by the use of digital video compression techniques.

There are two types of data compression methods: reversible and irreversible. Reversible compression can typically provide a compression ratio of 2:1 to 3:1, and furnishes a reconstructed image which is identical in every way to the original image. Irreversible compression allows higher compression ratios to be obtained at the cost of a reconstructed image that differs from the original. The extent of these differences depends on the compression ratio used and on the adequacy of the compression algorithm. Even if final diagnosis is to be performed using an image that has been reversibly compressed, irreversible compression will still play a critical role in reducing the time and cost associated with image browsing and other functions which require quick access to large amounts of data that are stored at a remote location. For common archiving media such as the digital audio tape (DAT) with a transfer rate of 400 KB/sec, at least a 20:1 compression for angiogram video is desired in order to achieve real time display. In this study, with the high image quality requirement, we have performed irreversible compression at a 20:1 ratio with the aim of comparing the approach we have developed based on the block discrete wavelet transform (DWT) [1] to the MPEG I [2] (Moving Picture Experts Group) standard which is a video compression method based on the block discrete cosine transform (DCT) and currently used for many non-medical video application.

This paper is organized as follows: section II describes the work performed, section III presents the discussion and section IV is the conclusion.

II. DESCRIPTION OF WORK PERFORMED

DCT-based methods such as MPEG I or II are experiencing widespread use in nonmedical applications of video compression. Although the block DCT is quite suitable for these applications, it has the disadvantage of producing block-like image artifacts that could mask or be mistaken for pathology in medical images. The approach that we have taken is to design an algorithm that in contrast with the block DCT does not partition the image into blocks for coding, thereby significantly reducing artifact generation in the reconstructed image.

In the compression experiments we performed, a MPEG I simulation program based on ISO 11172 international standard was used. We adopted the standard approach of defining an intra-dependent group of pictures (GOP) consisting of several (twelve in the studies we performed) consecutive image frames. The first frame in each GOP was coded independently; in other words no information from nearby frames was utilized. The remaining frames in each GOP were predicted by motion estimation and error compensation, with the error information then coded using a transform. We performed compression using two versions of MPEG I coding as well as with the full-frame DWT algorithm. In one version of MPEG I , we used forward prediction only, in which motion compensation is performed using a single previous frame. In the second version we utilized bidirectional prediction, in which prediction is performed using frames that occur both before and after the frame of interest. Bidirectional prediction is more challenging in terms of memory requirements and computational complexity, but it has the advantage of producing more efficient prediction and therefore gives better compression. In both the forward-predicted and the bidirectional-predicted MPEG I implementations, coding of the prediction error is accomplished using a block DCT. It is this block-based approach that is responsible for the introduction of block artifacts in the reconstructed image.

For the DWT algorithm, a biorthogonal basis[3,4] was used to obtain a multiresolution representation of the image. An example of the decomposition that results is shown in Figure 1(b); the original image from which this example was generated is shown in Figure 1(a). In the wavelet transformed image of Figure 1(b), a reference signal representing the reduced resolution version of the original image is maintained in the upper left corner, with the other regions of the figure representing various combinations and resolution levels of high and low spatial frequencies. The wavelet domain representation itself illustrated in Figure 1(b) does not introduce any compression. Compression is obtained by quantizing the transformed data using a combination of scalar quantization followed by arithmetic coding, or by alternative techniques such as vector quantization, run length coding, and Huffman coding. In our implementation we used scalar quantization and arithmetic coding because they enable high compression efficiency at relatively low computational complexity. In coding the prediction error for the DWT algorithm, we performed the additional step of adaptively identifying those regions of the prediction error that would be likely to cause artifacts, and investing a greater amount of the error coding bandwidth in these signals at the expense of less important regions of the prediction error image.

The adaptive error coding scheme could be summarized as follows:

1. During motion estimation, a threshold for cost function (sum of the absolute difference of the error block) is set in order to decide whether the error information inside the block is essential for error compensation or not.

Fig. 1(a) Original Angiogram

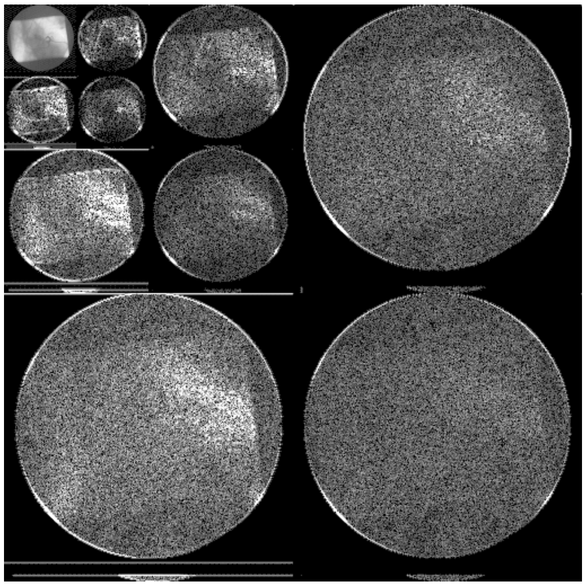

Fig. 1(b) Three level wavelet decomposition of Figure 1 (a).

2. if cost < threshold, no error information is encoded. else if cost ≥ threshold, then block classification is performed.
3. If the error block is classified as “hard to encode”, a block of the original information is encoded in order to achieve higher coding gain. Otherwise, the error information is encoded for error compensation.

Using the three algorithms described above (forward-predicted MPEG I, bidirectional-predicted MPEG I, full-frame DWT with adaptive error coding) we performed compression at 20:1 on five different angiogram data sequences containing a total of over 500 image frames. Each frame had a resolution of 512 by 512 pixels, with 8 bits gray-level intensity for each pixel.

III. DISCUSSION

Figure 2(a) shows an example of a reconstructed image after 20:1 compression using the DWT algorithm. An error image showing the difference between the reconstructed image (Figure 2(a)) and the original image (Figure 1(a)) is shown as Figure 2(b). This error image has been amplified and zoomed to show detail. For comparison, error images corresponding to the same frame under bidirectional MPEG I coding and forward-predicted MPEG I coding are displayed as Figures 2(c) and 2(d) respectively. In all of these error images (Figs. 2(b)-2(d)) the same zooming factor and amplification were used. The reconstructed image of Figure 2(a) is clearly of high quality, and its corresponding error image (Figure 2(b)) displays no evidence of block artifacts. This contrasts quite strongly with the error images from the block DCT-based schemes (Figures 2(c), 2(d)) in which block boundaries are clearly in evidence. These block-correlated errors are present in a reconstructed image as distortions along block boundaries which can make diagnoses such as the percentage stenosis inaccurate.

An additional comparison is furnished by examining the normalized mean square error (NMSE) for the algorithms under study. Although NMSE does not always correlate precisely with perceived image quality, in combination with illustrations such as those shown in Figures 1 and 2 it can provide useful supplementary information regarding the extent and growth of image distortion. A plot giving the NMSE for each

Fig. 2(a) Reconstructed image from DWT algorithm after 20:1 compression

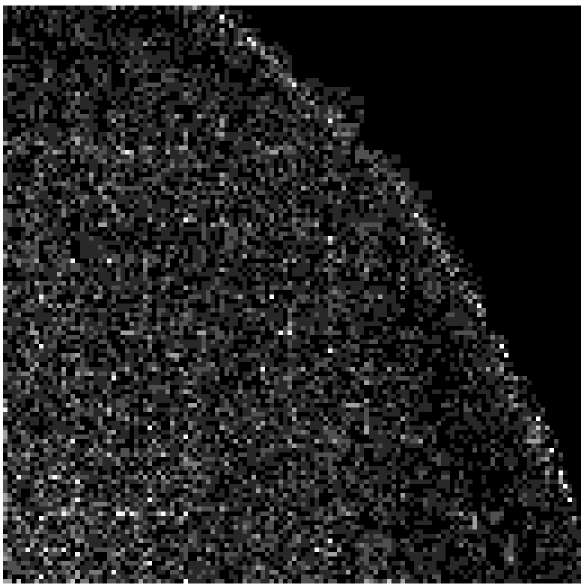

Fig. 2(b) Detail of amplified error image from Figure 2(a).

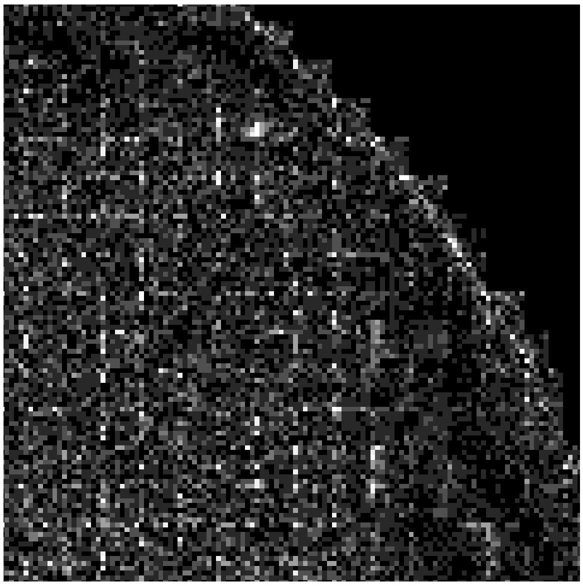

Fig. 2(c) Detail of amplified error image from MPEG coding at 20:1 using bidirectional prediction.

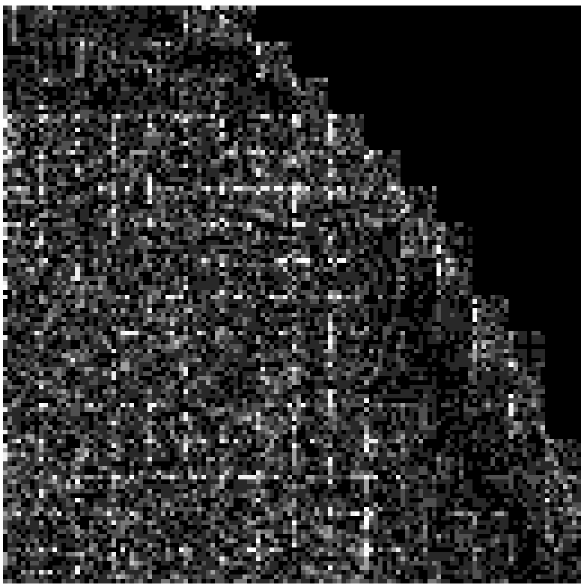

Fig. 2(d) Detail of amplified error image from MPEG coding at 20:1 using froward prediction. The same amplification was used for Fig. 2(b),(c) and (d).

of the three algorithms for a segment of a typical angiogram sequence is presented as Figure 3. The horizontal axis gives the frame number. In this case, 37 frames, corresponding to just over one second of data are considered. The vertical axis indicates the NMSE in percent. Curves are presented for both MPEG I approaches as well as for the DWT approach. The sawtooth appearance of the curve for the forward-predicted MPEG I coded data occurs because the error within each 12-frame GOP will accumulate as distance from the non-motion-compensated first frame increases. The mean and standard deviation (taken over the 37 frames in the sequence) of the NMSE are given in Table I. The superior image quality of the deviation (taken over the 37 frames in the sequence) of the NMSE are given in Table I. The superior image quality of the full-frame DWT approach is supported by the data of Table I and Figure 3.

TABLE I: NMSE comparison for MPEG and DWT at 20:1 compression

Compression Method	Average NMSE(%)	Standard Deviation
MPEG I (forward predication only)	0.0244	0.1296
MPEG I (bidirectional prediction)	0.0216	0.0359
Full frame DWT	0.0193	0.0275

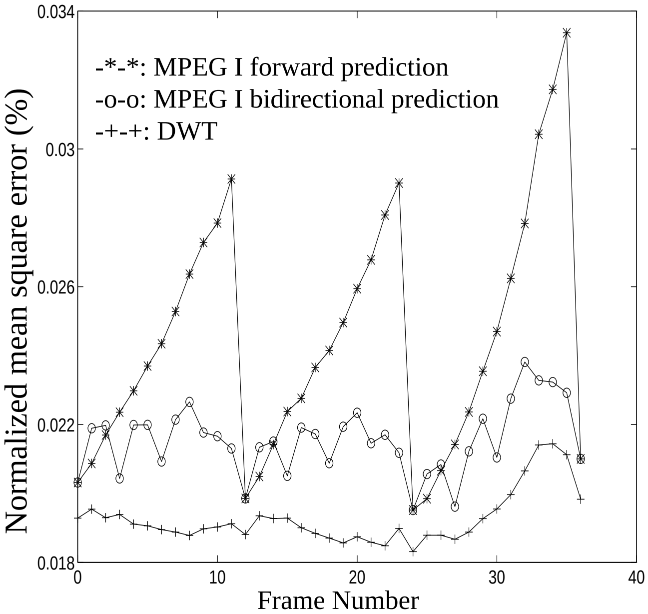

Fig. 3 NMSE of reconstructed sequences using MPEG I and DWT coding at 20:1 compression

Consider the saving obtained by using adaptive error coding, Figure 4 shows the plot of the compressed size by block classification. The horizontal axis gives the standard deviation and the vertical axis indicates the compressed size by using arithmetic coding. We have found the standard deviation possesses a good block classification capability. This can be attributed to the fact that block artifacts tend to increase the entropy, resulting in larger compressed size. The standard deviation is a good indicator of the level of variation in the block. Whenever the standard deviation equals zero, only an original image is encoded. On the other hand, whenever the standard deviation increases, more blocks will be categorized to be error encoded blocks. However, we could find a global minimum point which gives the highest savings at about the standard deviation of 1.5 to 3. This value will be used as the threshold for determining whether to encode the error block or original image since the characteristics of the adjacent frames in the whole video sequence are similar.

Although these data correspond to a particular test sequence, we found similar results for all of the angiogram sequences that we analyzed.

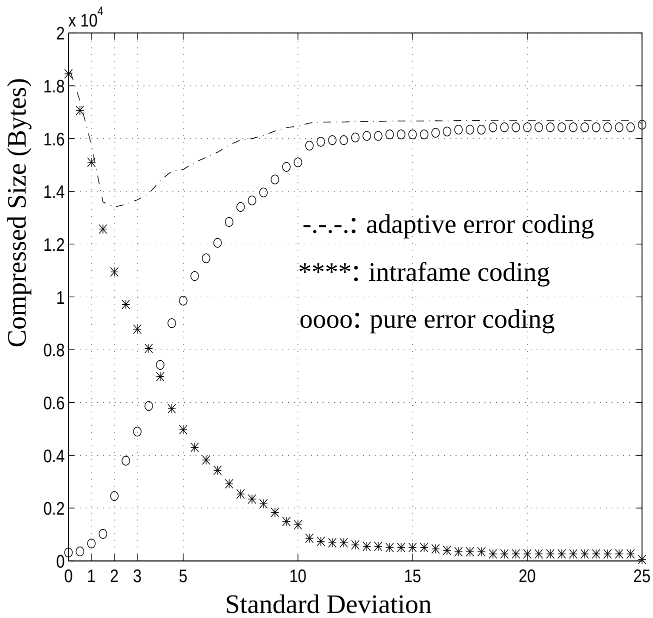

Fig. 4 Plot of compressed size for angiogram video coding using block classification.

We attribute the reduction in block artifacts obtained via the DWT algorithm to several reasons. First, the DWT decomposition, which is the basis for the coding algorithm, is being performed on a full-frame basis. Thus, in this stage of the coding there is no opportunity for block artifacts to be introduced. Unfortunately, even when the transform is full-frame, it is still necessary to perform motion compensation using an approach in which some segmentation of the image is implied. Although promising results have been obtained on object-based image representations [5] in which the regions of motion are based on actual objects in the image, we believe that these techniques have not yet reached their full maturity, and that block-based motion compensation still gives more consistent performance. Although our use of block-based motion estimation does introduce block artifacts into the initial prediction image, we prevent these artifacts from surviving in the final reconstructed image, by adaptively searching the prediction error for regions in which these artifacts appear. Greater resources in the error coding are then allocated to these regions, with the effect that the artifacts are eliminated upon reconstruction.

The idea of treating medical images using a full-frame rather than a block transform is not new. In fact, previous studies of irreversible compression have reported encouraging results using a DCT which is applied to the entire frame rather than on individual blocks [6,7]. It is also possible to apply the DWT on a block by block basis rather than in a full-frame implementation as we have presented here. The decision to use a full-frame approach is of course motivated by the desire to reduce artifacts. The reason for using the DWT instead of the DCT is that the DWT can be implemented using very low complexity hardware if the correct filters are chosen, and the decomposition furnished by the DWT is more natural in terms of organizing information in a way similar to that used by the human visual system.

Although in this study we used NMSE as a distortion measure, a receiver operating characteristic (ROC) analysis is needed before definitive conclusions regarding the relationship of diagnostic accuracy to medical video compression can be established. We are currently planning to perform such a study as a follow-up to the work described in this paper.

IV. CONCLUSION

Angiogram images can be compressed with high efficiency and without introducing block artifacts in the reconstructed image when an algorithm based on a full-frame discrete wavelet transform (DWT) and adaptive prediction error conditioning is utilized. In contrast with block DCT algorithms in which block artifacts are introduced at both the coding and the motion prediction stages, the full-frame DWT algorithm introduces these artifacts only in the motion prediction stage. By adaptively searching the prediction error to identify the locations of these artifacts and by modifying the error coding accordingly, it is possible to eliminate them from the final image. While it is premature to make conclusions regarding acceptable compression ratios in the absence of ROC studies, these results suggest that approaches based on the full-frame DWT have strong promise to provide both high image quality and high compression efficiency when applied to coronary angiograms.

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