COMPARATIVE STUDY OF COMPRESSION METHODOLOGIES FOR DIGITAL ANGIOGRAM VIDEO

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ABSTRACT

In this paper an experimental study of different compression methodologies for digital angiogram data is performed. The need for compression is identified, and various aspects of the compression procedure are examined. Traditional motion compensation strategies are considered, and their level of effectiveness with angiogram video is assessed.

1. INTRODUCTION

Conventional analogue approaches to the storage of angiogram video are largely being superseded by their digital counterparts. The advantages of this new approach include the potential for higher quality images, no degradation in quality over time, faster access, improved display management and ease of transmission, to name but a few. This in turn creates exciting new possibilities, greatly improving efficiency, while at the same time relaxing geographical constraints on the access of the data allowing a consultant in another hospital, or even another country to review an angiogram sequence remotely. Unfortunately the logistics concerning angiogram video, as with much medical imaging, makes such a vision hard to realise in practice. Typical image sizes are 512x512 (or even 1024x1024) pixels, taken at 30 frames/sec with at least 8 bits of resolution. A typical procedure may be of the order of 5 minutes resulting in approximately 2.5GB of raw data. At a constant data rate of 64Kbit/sec it would take 80 hours to transmit this quantity of data, and even at 10Mb/sec it would take 30 minutes. From this it is clear that a practical system for transmitting angiogram video from one hospital to another requires a high bandwidth connection, but even then a wait of 30 minutes may be considered unacceptable, especially if a semi-real-time diagnosis is required.

Matters may be improved considerably by compressing the video stream. Due to the sensitivity of the data however, only lossless or near-lossless algorithms can realistically be used. Unfortunately, the tight constraints imposed by lossless compression usually limit the compression ratio to about 2 or 3:1. This paper considers lossy approaches, with compression ratios of approximately 10:1. For diagnostic purposes, it is essential that the compression process causes no tangible loss of detail and introduces no noticeable artefacts which could be misinterpreted as being pathological in nature. Little research has been done specifically regarding the compression of angiogram video. Unfortunately given the unique structure of the data, video compression results relating to more conventional types of video (e.g. for digital television), for which there has been a great deal of research, do not necessarily apply here.

In this paper we look at both inter and intra-frame techniques, examining the specific challenges that angiogram video poses in terms of motion compensation, and considering both wavelet and discrete cosine transform (DCT) based coding schemes. More specifically the paper will consider;

1) The comparison of DCT and wavelet coders applied on a frame by frame basis (intra-frame).
2) The comparison of different motion compensation schemes for angiogram video, again considering both DCT and wavelet based coders.

Section 2 of this paper describes more fully the experimental framework, and section 3 presents the results which have been obtained. Section 4 presents a set of conclusions.

2. EXPERIMENTAL FRAMEWORK

The two coding schemes considered here are illustrated in Figure 1(a-b). The first is an intra-frame transform approach with an entropy coder. The second employs an inter-frame motion compensation feedback loop. In both cases the transform coder T is selectable to be either DCT based or wavelet based. The DCT coder uses blocks of 8x8 pixels and is based upon the JPEG standard [1]. The wavelet based approach uses a 5 level Daubechies 9-7 wavelet and a SPIHT coder [2]. In all cases the final bit stream is entropy encoded using the arithmetic coding technique.

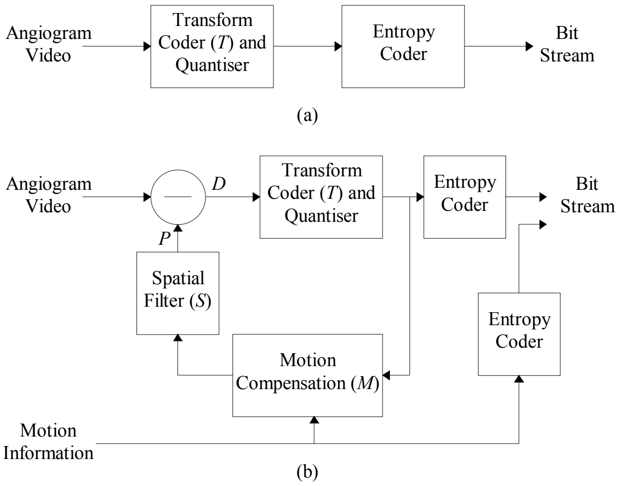

Figure 1: (a) Intra-frame coding scheme, (b) Inter-frame coding scheme.

In the case of Figure 1(b), the aim is to exploit temporal redundancy by utilising a motion compensation feedback loop. The two key stages in this particular feedback loop are the motion compensation block (*M*), and the low-pass spatial filter (*S*). The low pass filter employs a Gaussian operator which removes the majority of the high frequency spatial texture. This, as will be seen, is essential for angiogram images, because in its absence the motion compensation proves completely counter productive. The motion compensation block is selectable to one of the following schemes: block matching, global compensation or no compensation. The first case considers 16x16 pixel blocks, with a maximum horizontal or vertical displacement of 7 pixels in integer steps. This form of motion compensation is by far the most commonly used in conventional video coders. The second case considers a global motion compensation scheme based on a 6 parameter affine model which is estimated using the robust global motion estimation approach devised by Black and Anandan [3]. The third motion compensation approach is simply to assume no inter-frame motion at all. In this case the frame estimate seen at point *P* (Figure 1(b)), will be the low-pass filtered version of the previous frame.

A collection of results using the above framework are given in the next section to explore the effectiveness of the different coding schemes for the compression of angiogram video.

3. RESULTS

3.1 Intra-frame Compression Results

Results for the intra-frame compression experiments using the DCT and wavelet approaches are shown in Figure 2. These are presented in the form of a rate-distortion graph showing the resultant RMS distortion for a given output bit-rate. Note that for all of the results given, the input bit-rate is 8 bits/pixel.

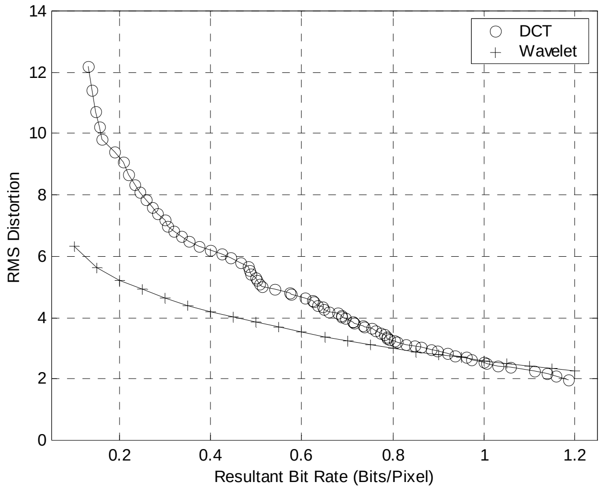

Figure 2: Rate-distortion curves for wavelet and DCT based methods.

What is clear from this is that for relatively low bit rates (<0.5 bits/pixel), the wavelet coder gives vastly superior RMS error rates than the equivalent DCT based algorithm. For bit rates of 0.5 to 0.75 bits/pixel the wavelet coder gives better results than the DCT method, but the difference is less significant. Above this both algorithms perform similarly, with the DCT based approach performing slightly better at bit rates above 1.1 bits/pixel. However bit rates larger than this become less useful as they begin to approach those which can be achieved using lossless methods. A typical reconstructed image for both DCT and wavelet based methods is shown in Figure 7. This is for an output data rate of 0.5 bits/pixel, and hence some artefacts are visible.

For use in a practical application, bit rates below 0.5 bits/pixel proved visually unacceptable (for both methods) since the resultant images contained noticeable artefacts. Only at bit rates of around 0.8-0.9 bits/pixel did the resultant images take on an appearance which was almost indistinguishable from the original. Furthermore for bit rates above 0.4 bits/pixel, the *blocky* artefacts often associated with JPEG proved no more visually distracting than the equivalent wavelet artefacts, and at bit rates which may be considered as medically suitable (of the order of 0.8-0.9 bits/pixel) the two algorithms gave very similar results, both numerically and visually.

3.2 The effect of spatial filtering on inter-frame prediction

Figure 6 shows two consecutive frames from a typical angiogram sequence. Visually, the difference between the two frames looks very small. One would expect therefore that the exploitation of this temporal dependency would equate to a reduction in the overall bit rate. However, it has been experimentally observed that the majority of this temporal redundancy lies in the low frequency image data. So much so, that it is required that a spatial filter be included in the motion compensation loop. The effect of this filter is graphically shown in Figure 3.

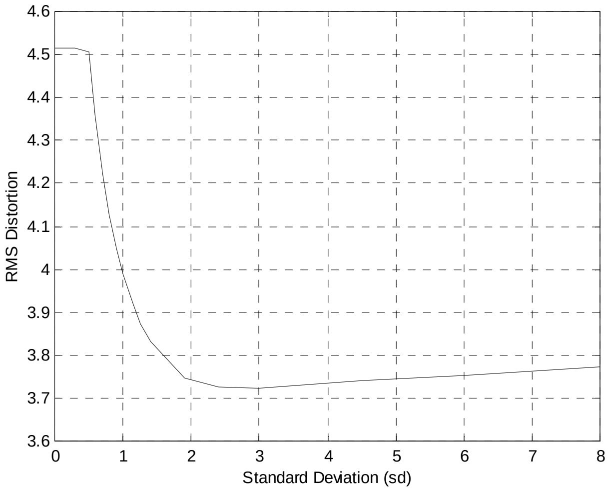

Figure 3: RMS prediction error for the wavelet coder using global motion compensation, as a function of the standard deviation of the spatial Gaussian filter.

For comparison, the baseline intra-frame distortion for this bit rate is 3.89. So as can be seen, without the spatial filter (*sd*=0), the effect of motion compensation is to significantly *increase* the RMS error. This effect is not only evident in the *global motion compensation* case, it is also closely mirrored for the *block matching* and *prediction only* cases too. The reason for this is the lack of temporal correlation in the high frequency image bands, resulting partially from the high frequency noise, and partially from the layered nature of the data in which multiple overlaid, semi-transparent layers all move differently. Hence to constructively utilise the temporal redundancy in angiogram sequences, spatial filtering is an absolute necessity. For the results presented in the next section a spatial filter with a standard deviation of 3.0 is assumed.

3.3 Motion compensation strategies

This section explores the effectiveness of methods in exploiting temporal redundancy through prediction and motion compensation. Figures 4 and 5 show the rate-distortion results for the wavelet and DCT based methods respectively. The *no prediction* curve corresponds to the intra-frame results given in section 3.1 and represents a baseline for comparison. Note that for the sake of relative comparison the resultant bit rate does not include the extra overhead of the motion parameters required for the motion compensation. In the *prediction only* and *global motion compensation* cases this overhead is either negligible or zero. In the case of block matching, this additional overhead will be of the order of 0.02 bits/pixel.

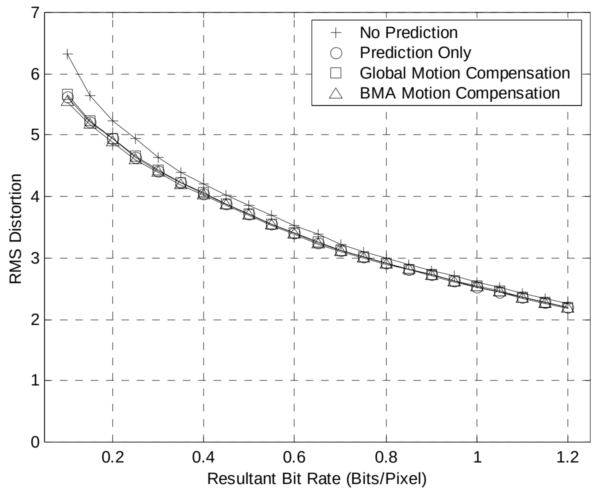

Figure 4: Rate-distortion curves for the wavelet based method using various motion compensation strategies.

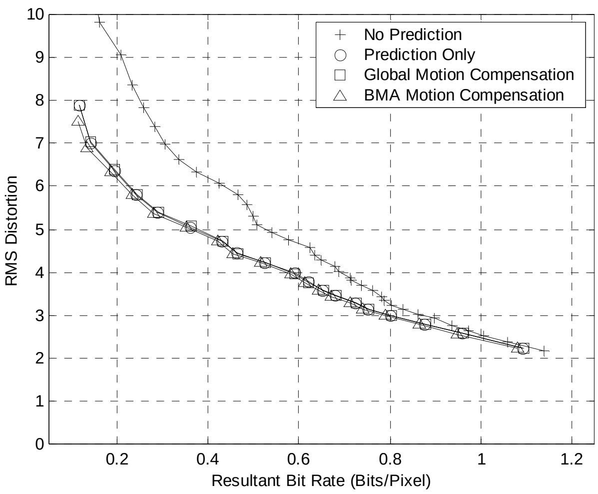

Figure 5: Rate-distortion curves for the DCT based method using various motion compensation strategies.

Several conclusions can be drawn from this which are relevant to both wavelet and DCT methods. Firstly the effect of prediction has a beneficial effect of the resultant error rate. Secondly the additional effect of motion compensating the prediction is very small. This is presumably due to the relatively small amounts of motion present, and the absence of high frequency components in the prediction at point *P*. In particular, this result clearly indicates that the not insignificant overhead of motion vectors introduced by block matching causes no significant corresponding improvement in RMS distortion error. Lastly, it is interesting to note that the benefits of prediction are smaller at higher bit rates. This effect is particularly apparent for the DCT based method for which the inclusion of a predictive feedback loop results in a fall in RMS error of 29% at a bit rate of 0.2 bits/pixel, with only a fall of 2% at a bit rate of 1.0 bits/pixel.

The effect of the different motion compensation strategies can best be illustrated by considering the difference between the current input frame and the prediction - the point labelled as *D* in Figure 1. Typical difference frames are given in Figure 8. In the background region (lower left half of the image), all methods seem to give similar performance. For the area of the image containing the arteries, the block matching approach seems superior, although as was seen in Figures 4 and 5, this equates to only a fractional improvement in RMS distortion.

4. CONCLUSIONS

This paper has examined the subject of video compression of angiogram data. The large sizes of angiogram sequences make compression highly desirable. Due to the diagnostic importance of such data, any compression scheme must either be lossless or near lossless. Such a requirement inevitably precludes very low bit-rate solutions as the quality of the resultant images is of insufficient quality. A ball-park figure of 0.8-0.9 bits/pixel has been identified as a rough guide for a suitable bit rate, resulting in high quality images. Whilst comparing the wavelet and DCT based coders, it became clear that at the high bit rates required, their performance was similar. The wavelet coder only gave superior results at bit rates lower than this, and performed extremely well at very low bit rates.

With the obvious temporal redundancy identified, the motion compensated prediction results may have proved as something of a surprise. Removal of the high frequency bands of the predicted image proved essential, as inclusion of these proved detrimental to overall performance. The resulting framework gave results which were better than the intra-frame equivalents, although the distinction was again more noticeable at lower bit-rates. Furthermore, at all bit rates the use of simple prediction proved just as beneficial as any of the motion compensated prediction approaches.

5. REFERENCES

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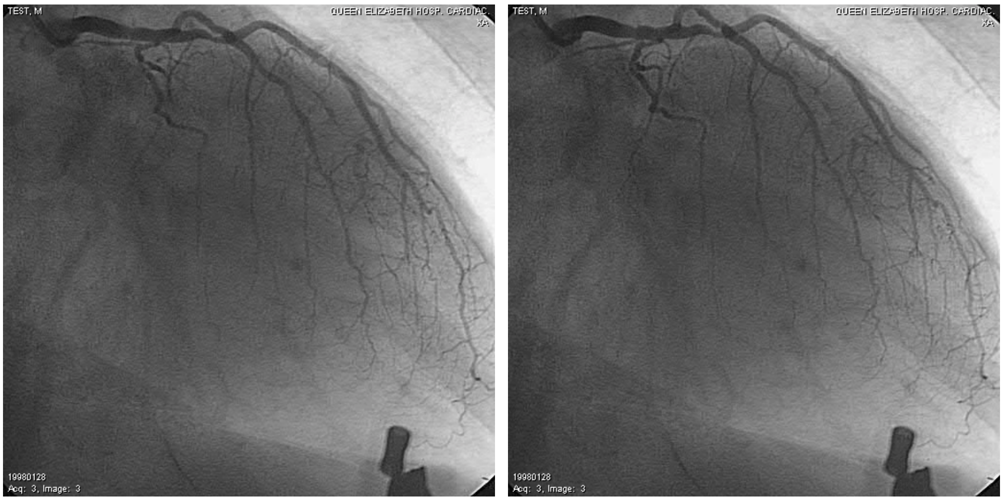

Figure 6: Illustrating the temporal redundancy contained within two consecutive frames of a typical angiogram sequence.

Figure 7: Intra-frame compression (compare with Figure 6 right) using wavelet (left), and DCT (right) at a data rate of 0.5 bits/second. Some artifacts are visible for both methods.

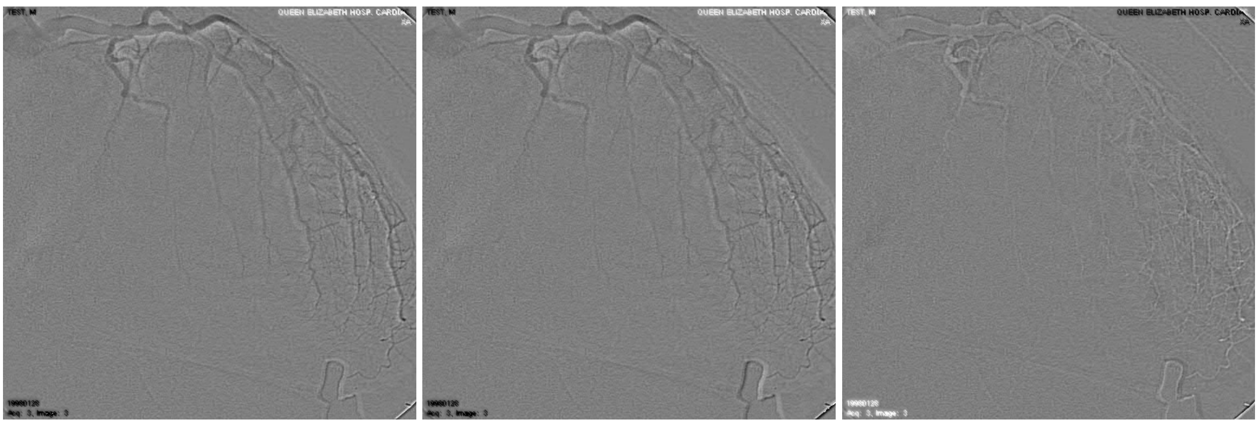

Figure 8: Input to the transform coder and quantisation block for the *prediction only*, *global compensation*, and *block matching* compensation schemes (left to right).