An Optimized Method for B-Mode Echocardiographic Video Compression Based on Motion Estimation and Wavelet

Nima Sahba[1], Keivan Maghooli[1], and Vahid Tavakoli[2]
[1]Department of Biomedical Engineering, Science and Research Branch, Islamic Azad University, Iran
[2]Department of Electrical and Computer Engineering, University of Louiville, USA

Abstract: *In this paper, a new approach for echocardiography image compression is developed. To achieve a high rate of image compression as well as preserving the image information, motion detection and wavelet transform are combined. In the first step, a Region Of Interest (ROI) is determined and the image is divided into several (8×8 pixels) blocks. Thereafter, the motion vectors of each block are estimated to predict the subsequent frame (predicted model frame). Additionally, the wavelet component is created by applying the wavelet transform to the main image (which should be predicted); whereas the extracted wavelet component is utilized as a predicted frame error compensator. Subsequently, entropy of the motion vectors of each block is extracted as a criterion to determine the level of quantization which is used for wavelet frame quantization. Wavelet frame is quantized based on the Lloyd's algorithm. Finally, the correlation of each block of the predicted model frame with the corresponding block of the main image is calculated to evaluate the rate of the accuracy of the result. If the calculated correlation is more than 0.5, an optimized combination of the predicted model and the corresponding block of the wavelet frame is utilized as the final block. Otherwise, the block of the wavelet frame is considered as the final result. The results were analyzed using PSNR, MSE, GLCM and expert-based quality image validation. The proposed algorithm was compared to standard MPEG standards, H.264 and VC1 which proved the out-performance of the proposed algorithm.*

Keywords: *B-mode echocardiography, video compression, motion estimation.*

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1. Introduction

Modern medicine is increasingly dealing with the data obtained from different imaging modalities such as ultrasound, X-ray and MRI for clinical diagnosis. This huge amount of data makes image compression methods of crucial importance. Clinical images are represented in a digital format to support reliable network transmission and efficient manipulation of medical information.

Echocardiography is the main imaging modality in the assessment of heart disease [3]. There are several modes for echocardiography imaging such as B mode, M mode, color Doppler, and pulse Doppler. Widespread application of echocardiography and the necessity for accurate compression of the echocardiogram images are the reasons to separately analyze the echocardiography-specific compression performance. Echocardiography video storage and real time tele-echocardiography are not possible using standard format such as Digital Imaging and Communications in Medicine (DICOM). Lossless compression methods are preferable but may not be efficient. DICOM does not suggest using lossy algorithms for radiologic images but permits lossy image compression for ultrasonic echo images due to their poor resolution [10]. There are a variety of methods for lossy image compression such as wavelet based and motion based image compression. The wavelet transform compacts image energy into smaller numbers of coefficients providing good localization characteristics in the spatial-frequency domain, which are ideal for compression [5, 9, 13]. Moreover, Motion estimation based algorithms are widely used in video compression such as MPEG standard, H.264 and VC1 methods. In MPEG standard, first the image is divided into macro blocks in addition to their motion vectors. Then the new frame is constructed using motion vector of each block and DCT transform. In H.264 standard, the size of each block changes according to the motion complexity to earn more efficiency [4]. Similar to MPEG standard, SMPTE 421M, also, known as VC1, is based on motion compensated transform. Entropy coding in VC-1 is achieved via an adaptive Huffman based table, while a computationally more complex Context Adaptive Binary Arithmetic Coder (CABAC) is used for entropy coding in H.264 [7].

In the field of echocardiography image compression, Vlahakis *et al.* [15] proposed a technique based on wavelet coefficients in three scales, performed on the segmented cardiac ultrasonic image. Their proposed method employed a geometric modeling technique to distinguish permanent background of echocardiography image. They showed that the method can improve the image compression ratio with respect to JPEG. A comparison between AVI and MPEG compression has been performed by Accardo *et al.* [1] on echocardiography sequences where the authors reported the out-performance of the MPEG echocardiography image compression. Afterward, Hang *et al.* [4] introduced a real-time three dimensional echocardiography compression technique based on three dimensional wavelet packet transform. A four dimensional arbitrarily sized echocardiography data compression method was presented by Zeng *et al.* [20] using both symmetric and anti-symmetric wavelets. Zaghetto *et al.* [19] proposed a modified JPEG algorithm using fuzzy logic for echocardiography image compression. They utilized the local characteristics of echocardiography images instead. Recently, Cavero *et al.* [3] proposed a technique for compression of different modes of echocardiography based on the characteristic of each imaging mode. According to their article, H.264 video compression is an effective method for echocardiography image compression. A multicenter validation study of echocardiographic compression is performed by Barbier *et al.* [2] based on MPEG-4 algorithms. They used subjective assessment of video quality by a group of cardiologists and concluded that MPEG-4 compression can preserve image quality while achieving high compression rate.

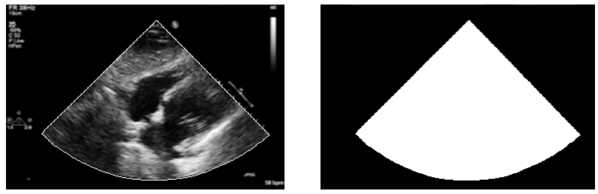
In the Wavelet based methods, high rate of compression can be achieved by high rate of quantization of wavelet components but this approach cannot preserve the image quality. In the motion based methods, higher image compression rate is achieved but it suffers from several artifacts such as block artifact [17]. It is noteworthy that, there is an inherent error in the velocity estimation methods that leads to inaccurate results [8, 13]. In this study, a combination of wavelet transform and motion based methods are used to achieve high rate of image compression while preserving high quality.

Due to the complexity of heart motion, combination of wavelet based and motion based compression can be effective to achieve high rate of compression while quality of echocardiography images. In this paper, a method base on the wavelet based and motion estimation based algorithm is proposed. The compression abilities of these two methods are efficiently combined to achieve a precisely compressed echocardiography.

This paper is organized as follows: First, the method uses a Region Of Interest (ROI) mask to distinguish variable and invariable data. Then, in sections 2.1 and 2.2, predicted model and wavelet frames are created respectively. In section 2.3, an optimized combination of the model frame and the wavelet frame is performed according to the correlation of the model and main frames. Afterward, the extracted ROI mask is applied. Experiments and comparisons are included in section 3 using numerical analysis.

2. Method

Ultrasound modalities produce fan-shaped images containing invariable information which is not necessary to be analyzed in each frame. Therefore as a preprocessing step, a ROI mask was defined to apply to the following steps. According to the Vlahakis *et al.* [15] determining three points is enough to extract fan-shaped ROI which can be modeled as a sector of circle and this paper uses the same approach [15]. The results of fan-shaped segmentation and ROI mask are shown in Figure 1.



a) Fan-shaped segmentation. b) ROI mask.

Figure 1. Region of Interest extraction.

It is possible to achieve the advantages of both wavelet based and motion based compression, using a combined framework. The proposed method in this paper consists of three steps as following: according to the flowchart in Figure 2:

1. Predicted model creation.
2. Wavelet frame creation.
3. Combination of the predicted model frame and the wavelet frame.

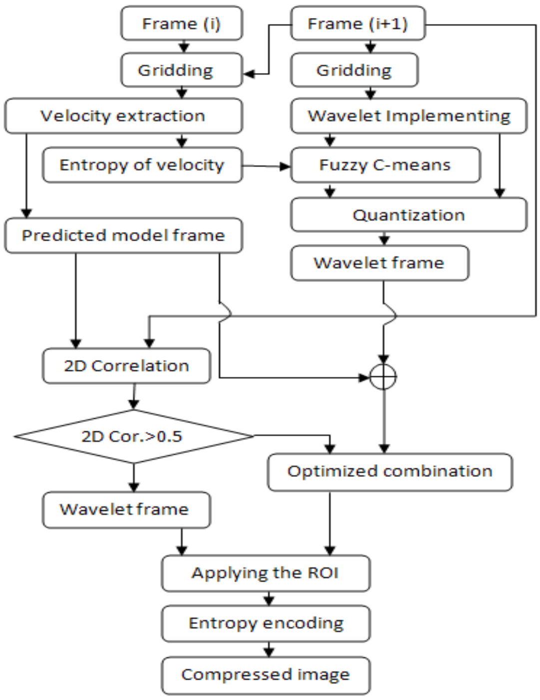


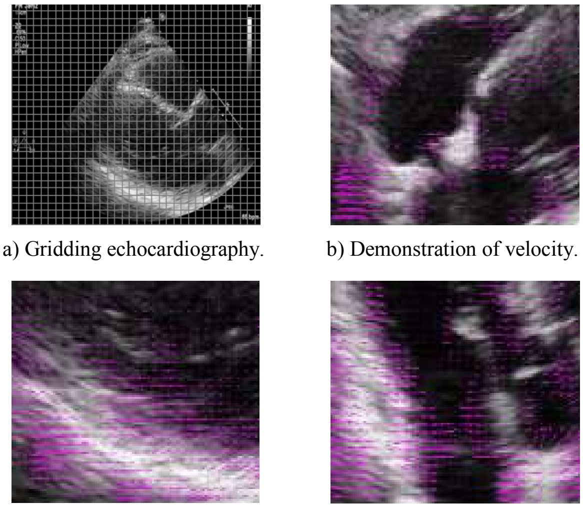
Figure 2. Flowchart of proposed algorithm.

2.1. Predicted Model Creation

In the first step, the image is divided into (8×8 pixels were selected practically) blocks (gridding) and the motion vector is extracted for each block. Optical flow as an efficient cardiac motion extraction is utilized to extract the motion vector of each frame [12]. Optical flow presumes gray level (intensity) constancy between two consecutive frames. According to the intensity constancy assumption, the following formulation previously presented by Lucas-Kanade should be minimized [6, 12]:

$$\sum W^2(x)[E_x u + E_y v + E_t]^2 \tag{1}$$

Where E is pixel intensity with gradients toward spatial (E_x, E_y) and temporal (E_t) dimension, α is a weighting parameter, u is the velocity toward the x-axis, v is the velocity toward the y-axis and finally w is a weighted window. Subsequently, the next frame is predicted according to the estimated motion vector of each block which is named predicted model frame. By warping each block in accordance with its motion vectors of it, the predicted model frame is constructed.



a) Gridding echocardiography. b) Demonstration of velocity.

c) Demonstration of velocity. d) Demonstration of velocity.

Figure 3. Motion estimation.

2.2. Wavelet Frame Creation

In the second step, the wavelet decomposition is applied to each block of the main frame (which should be predicted) and is used as error compensator of the predicted model frame. The level of wavelet coefficient quantization is computed according to the complexity of the motion vectors of each block achieved by computing of entropy. The entropy of motion of each block is defined as follows:

$$En = -\sum p \ln p \tag{2}$$

Where p contains the histogram counts of each blockmotion amplitude.

Fuzzy C-Means (FCM) is utilized to classify four levels of quantization (2, 4, 6 or 8) of wavelet coefficients based on the complexity of each block motion, while lower level of quantization means less motion complexity. FCM is based on minimization of the following objective function:

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} (u_{ik})^m \left\| x_i - c_j \right\|^2 \tag{3}$$

Where c_j is the center of the *j-th* cluster, x_i denotes to the *i-th* wavelet coefficient value and $\| \|^2$ is the square Euclidean distance between x_i and c_j. The degree of fuzziness is determined by $(u_{ik})^m$ [11]. As mentioned before, according to the motion complexity of each block the numbers of clusters are assigned to be 2, 4, 6 or 8.

Subsequently the wavelet coefficients of each block are quantized using Lloyd's algorithm to achieve the wavelet frame. Lloyd method as a non- uniform quantizer is an efficient algorithm for wavelet coefficients quantization. In the non-uniform quantization, sampling rate is increased in regions with greater data density and vice versa [10, 16].

2.3. Combination

Two dimension correlation between each block of the predicted model frame (based on the motion) and corresponding block of the main frame (which should be predicted) is calculated using the following formulation:

$$corr = \frac{\sum_{k=1}^{K} \sum_{l=1}^{L} (M(k,l) - \bar{M})(I(k,l) - \bar{I})}{\sqrt{\left[\sum_{k=1}^{K} \sum_{l=1}^{L} (M(k,l) - \bar{M})^2\right]\left[\sum_{k=1}^{K} \sum_{l=1}^{L} (I(k,l) - \bar{I})^2\right]}} \tag{4}$$

Where M and I are the predicted model frame and main frame respectively. K and L denote to the size of each block which are considered to be 8×8.

If the 2D calculated correlation is more than 0.5, an optimized combination between the block of the predicted model frame and corresponding block of wavelet frames is performed. Otherwise, it means the block of predicted model frame is not a good representation of the corresponding block in the main image. Finally, ROI mask is applied on the wavelet frame or optimized combination of wavelet frame and predicted model frame to select the appropriate data which is necessary to be saved. If there is an overlap between white region of ROI and the computed blocks of wavelet frame or model frame, these blocks will be saved. A flowchart of the proposed method is shown in the Figure 2.

2.3.1. Optimization

If the calculated correlation between the block of predicted model frame and the block of the main frame is more than 0.5, optimized combination is performed. In the optimization framework, the difference between the reconstructed block (sum of the α and $1\text{-}\alpha$ coefficients of predicted model and wavelet frames respectively) and main corresponding block should be minimized. The error function is defined as following:

$$E = \left|\alpha M + (1-\alpha)W - I\right|^2 \quad (5)$$

Where α is a coefficient which shows the weight of the combination of the predicted model and the Wavelet frames in the $0<\alpha<1$ domain. M and W are corresponding to the mean of gray levels of predicted model and wavelet frames in each corresponding block respectively and I is the main image.

By taking the derivative of the error function with respect to the α, the optimized value is computed as follows:

$$\alpha = \frac{\left|I - W\right|}{\left|M - W\right|} \quad (6)$$

If denominator is smaller than the nominator, corresponding block of predictive model and wavelet frames are similar and the value of α is more than one. In this situation the error compensator wavelet frame is not effective, therefore α is considered to be 1.

3. Result

We made use of 14 different 2D echocardiography series (totally 1226 frames) acquired from normal or patients. The resolution of each frame was 640×480 pixels (8 bit per pixel). Both quantitative and qualitative evaluations were implemented to assess the results. An expert cardiologist approved the quality of echocardiography frames after reconstructing the frames using the proposed method.

The results of the predicted model frames show the blocking artifact i. e., some blocks appear in the reconstructed predicted model frame as shown in Figure 4. Also, the predicted model frame is constructed based on the velocity estimation which practically has the error of estimation. However, the extracted wavelet frames as the error compensator can effectively reduce the error. Figure 5 depicts the performance of proposed algorithm in the combined framework of wavelet and predicted model frames.

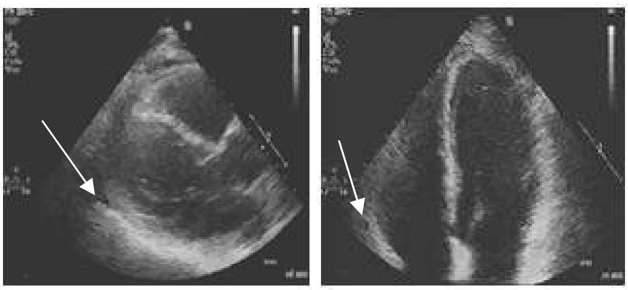
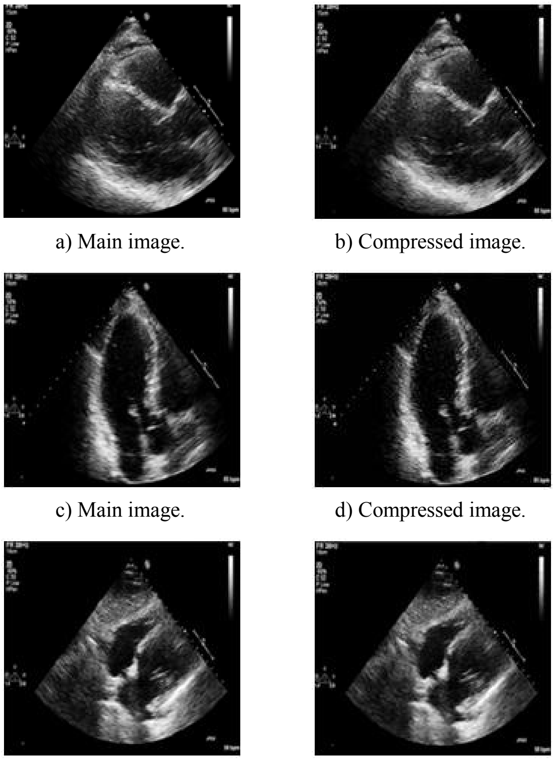


Figure 4. The artifact of high level image compression based on wavelet method.



a) Main image. b) Compressed image.

c) Main image. d) Compressed image.

e) Main image. f) Compressed image

Figure 5. Image quality comparison.

Different mother wavelets were evaluated to see which one of them is better for echocardiography image compression shown in Table 1.

Table 1. Evaluation of different mother wavelets.

Mother Wavelet	Mean of PSNR+ Standard Deviation	Mean of NAE+ Standard Deviation
Daubechies 7	35.31 ± 3.2	0.11 ± 0.008
Daubechies 5	36.23 ± 1.9	0.082 ± 0.001
Daubechies 3	35.88 ± 2.8	0.102 ± 0.004
Daubechies 1	35.51 ± 2.4	0.106 ± 0.002
Biorthogona1 6.8	36.42 ± 2.1	0.079 ± 0.001
Biorthogona1 4.4	35.99 ± 2.1	0.086 ± 0.003
Biorthogona1 2.8	36.33 ± 2.0	0.081 ± 0.001
Biorthogona1 2.2	36.11 ± 2.1	0.089 ± 0.001
Biorthogona1 1.5	35.51 ± 2.3	0.095 ± 0.002
Coiflets 5	35.73 ± 2.2	0.092 ± 0.003
Coiflets 3	35.84 ± 2.2	0.094 ± 0.003
Coiflets 1	36.32 ± 1.9	0.082 ± 0.001
Symlets 7	35.18 ± 3.1	0.14 ± 0.007
Symlets 5	35.54 ± 2.9	0.12 ± 0.004
Symlets 3	35.82 ± 2.6	0.097 ± 0.004
Haar	35.52 ± 2.5	0.10 ± 0.003

The proposed algorithm was quantitatively evaluated with regard to the Peak Signal to Noise Ratio (PSNR), Normalized Average Error (NAE) and compression ratio using the following formulation:

$$PSNR = 10log_{10}\left(\frac{R^2}{MSE}\right) \quad (7)$$

$$MSE = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}[I_1(m,n) - I_2(m,n)]^2}{M \times N} \quad (8)$$

$$NAE = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N} I_1(m,n) - I_2(m,n)}{\sum_{m=1}^{M}\sum_{n=1}^{N} I_1(m,n)} \quad (9)$$

Where *R* is the maximum gray level area in the image and MSE demonstrates the mean square error. I_1 and I_2 are the $M \times N$ primary and compressed pixel intensity of frames respectively.

The results of proposed method prove its performance in echocardiography compression with respect to the other popular compression methods such as MPEG standard, H.264 and VC1 Shown in Table2.

Spatial relationship of the gray levels is an important criterion which should not be changed by compression processes, because it can be effective in diagnosis precision of cardiologist. The Gray Level of Co-occurrence Matrix (GLCM) represents the image by computing how often pairs of pixel with specific values and in a specified spatial relationship occur in an image. Therefore, GLCM as the gray level vicinity evaluator is used to see whether the information vicinities are preserved [18]. Table 3 shows the correlation of GLCM of the compressed and main frames in 0, 45, 90 and 135 degrees. As it can be seen in Table 3, the proposed method can keep spatial relationship of gray levels more efficiently.

Table 2. Comparison of different methods for echocardiography compression.

Method	Mean PSNR+ Standard Deviation	Mean of NAE + Standard Deviation	Compression Ratio
MPEG Standard	31.61 ± 2.4	0.284 ± 0.003	0. 23 bit/pixel
Proposed algorithm	36.42 ± 2.1	0.079 ± 0.001	0. 08 bit/pixel
H.264 Standard	34.21 ± 1.6	0.102 ± 0.004	0.14 bit/pixel
VC1	34.13± 1.4	0.104± 0.004	0.13 bit/pixel

Table 3. Mean of correlation between the GLCM of compressed and the GLCM of main frame (compression rate according to the Table 2).

Method	0 degree	45 degree	90 degree	135 degree
MPEG Standard	0.9981	0.9973	0.9977	0.9980
Proposed algorithm	0.9997	0.9995	0.9994	0.9993
H.264 Standard	0.9995	0.9993	0.9994	0.9989
VC1	0.9992	0.9993	0.9988	0.9991

4. Discussion and Conclusions

Several mother wavelets such as Coiflets, Daubechies, Biorthogonal, Symlets and Haar families were used for the assessment the results. In general, Biorthogonal mother wavelets showed better results with respect to the other methods. However, the results of Symlets and Daubechies mother wavelet were almost similar.

Regarding to the aim of the image compression, higher rate of image compression is achieved while the image quality is preserved. In the wavelet based methods, there is a tradeoff between image quality and rate of compression. In the motion based image compression methods, it is possible to achieve a high rate of image compression but the inherent error of motion estimation methods is inevitable. Consequently, a high rate of compression has been achieved in this study by combining the wavelet and motion based methods, while preserving the image details. The results prove the efficiency of the proposed method as a specific technique for echocardiography video compression.

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Nima Sahba is pursuing the PHD degree at department of biomedical engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran. He received his BS and M.S. from the same university (2001 - 2008). He had been research assistant at Research Center for Science and Technology in Medicine (RCSTIM), Tehran, Iran for 3 years. His research interests are: Cardiovascular imaging, Medical image compression, Mammography mass detection.

Keivan Maghooli has been the Assistant Professor at Department of Biomedical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran. He is a PhD Scholar at mentioned Department. He holds MS (CS) degree in Biomedical Engineering from Tarbiat Modares University, Tehran, Iran. He has more than 10 years of experience including teaching graduate and undergraduate classes. He also, leads and teaches modules at BSc, MSc and PhD levels in Biomedical Engineering.

Vahid Tavakoli joined a joint degree program of MS Biomedical Engineering and MD Medicine (Honored double degree) in 1998. He is currently pursuing his PhD program in Electrical and Computer Engineering department, University of Louisville, KY, USA. His research interests are: Cardiovascular Motion Detection, Medical Robot Vision, Image-Guided surgery, Optical Flow and Registration.