Wavelet based vector quantization with tree code vectors for EMG Signal compression

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Abstract -This paper discusses a wavelet-based Vector Quantization technique for the compression of Electromyogram (EMG) signals. Wavelet coefficients, obtained from EMG signal samples, are arranged to form a set of vectors called Tree Vectors (TVs), where each vector has a hierarchical tree structure. Vector quantization is then applied to these tree vectors for encoding, which uses a pre-calculated codebook. The encoded vector is a set of indexes of the codebook vectors. The codebook is updated dynamically using distortion constrained codebook replenishment method. Finally the signal is decoded using a copy of the same codebook available with encoder. Tests were performed on EMG records obtained from PGI Chandigarh. A good quality of reconstructed signal and sufficient compression is achieved. An average CR of 20.64:1 at PRD of 6.12% is obtained by this technique.

Key word-**:** Electromyogram (EMG), Tree vector (TV), Vector quantization (VQ), Discrete wavelet transform (DWT). Distortion constrained codebook replenishment (DCCR)

1.Introduction

Various biomedical signal like, EMG (Electromyogram), ECG signal (Electrocardiogram), etc are very important physiological signals, which are used to diagnose different human disorders. EMG is an electrical recording of the muscle activity [1]. Muscles are stimulated by motor neurons. The stimulation causes the electrical activity in the muscles, which in turn causes contraction. A needle electrode inserted into the muscle detects the electrical activity. EMG can determine whether a particular muscle is responding appropriately to stimulation or not. Therefore, EMG is used to diagnose various neuromuscular problems and movement disorders [2] [4].

The online storage and transmission of these signal increases with the increase in sampling rate, sampling resolution and recording time. Gradually, increase in the storage space and bandwidth requirements of these signals become a problem due to the large data size. Removing the redundancy and preserving the necessary information solve the problem. Various data compression techniques used for biomedical signals based on this principle are categorized as follows.

Direct data compression technique: This method eliminates the redundancy in the data sequence by examining a successive number of neighboring samples. Various prediction or interpolation algorithms are used for this purpose e.g. Tolerance comparison technique, differential pulse code modulation (DPCM), ADCPM, Entropy encoding techniques etc [3]. Various methods based on these techniques are AZTEC(amplitude zone time epoch coding), CORTES, the turning point technique etc.

Transform data compression technique: Transform of a signal is obtained to find frequency spectra. The transform coefficients are then encoded to reduce the amount of data needed to represent the original signal. Various methods like Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), KLT are being used to encode biomedical signals[5]. DWT has become popular due to good compression and quality of reconstructed signal. The coefficients obtained from DWT can further be processed to increase the amount of compression using Embedded Zero Tree wavelet (EZW), vector quantization (VQ), dynamic vector quantization using single codebook and SPIHT etc.[6,7].

The wavelet based ECG compression technique proposed by Zhitao Lu, Dong, Youn Kim, and William A. Pearlman , known as set partitioning in hierarchical trees (SPIHT) where wavelet coefficients are arranged in parents off spring tree in order to exploit the spatial self similarity property of wavelet coefficients across sub bands is quite good therefore this property along with tree structure can be used to obtain tree code vectors for vector quantization technique.[5,8] .

Also parameter extraction based compression technique where a particular parameter/characteristic of the signal is extracted and utilized for classification based priori knowledge of the signal features.

The rest of the paper is organized as follows. Section 2 describes methodology along with a brief overview of VQ technique. In Section3, the results, obtained by varying various coding parameters, and its analysis is given. Finally, conclusion is discussed in Section 4.

2.Methodology

Wavelet Transform has got some well known properties like spatial frequency localization and multiresolution analysis, energy compaction and cross sub band similarity etc. therefore WT is known as one of the most powerful tools for Digital signal processing and especially for data compression. DWT is applied on the EMG samples to obtain the wavelet coefficients. The wavelet coefficients are then converted to a matrix of vectors. Each vector has a hierarchical structure and is called a Tree Vector (TV). The TVs are then encoded by using Vector Quantization technique (VQ). VQ uses a pre-calculated codebook for encoding the signal. The encoded vector represents the indices of the codevectors (vectors in the codebook), which matches best with the tree vectors. Finally the signal is decoded by using the identical codebook (as on the encoder side) to get the reconstructed signal.[6] .

The original and the reconstructed signal are compared to evaluate the efficiency of this method. For this purpose, a distortion measure i.e. Percentage root mean square difference (PRD) and compression measure i.e. Compression Ratio (CR) has been used[2]. The block diagram of the encoder/ decoder is shown in fig.1.

2.1 DWT- Wavelet transform shows good localization in both frequency and time domain. It has fine frequency resolution and coarse time resolution at low frequencies and has fine time resolution and coarse frequency resolution at high frequencies[9]. Since this matches with the characteristics of the EMG signal, it makes wavelet transform well suited for the time frequency analysis. To illustrate the decomposition of the original signal with frequency components into various sub bands, let h(n) represents the low pass filter and g(n) represents the high pass filter. The two filtered outputs are downsampled by two to obtain two subbands $X_{L,1}$ and $X_{H,1}$. During reconstruction phase, $X_{L,1}$ and $X_{H,1}$, are up sampled by two and passed through another set of *synthesis filter pair* [l,h], to obtain the reconstructed signal [10].

The process of decomposition of the original signal in different frequency subbands is repeated 'n' times. By the n-level wavelet decomposition, the original signal x(n) is decomposed into n+1 subbands, i.e. $X_{L,n}$, $X_{H,n}$, $X_{H,n-1} \ldots_{H,2}$, $X_{H,1}$. A mother wavelet function has to be chosen for wavelet transform along with the decomposition level (n). The wavelet to be chosen depends on the characteristics of the signal. Finally, large number of detailed coefficients and few approximation coefficients are obtained[10].

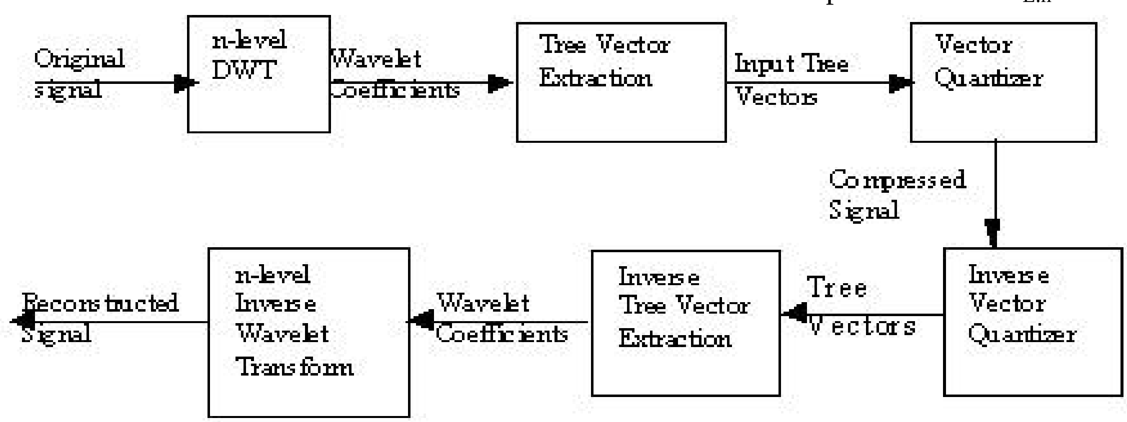

Fig1: Block Diagram of WT-based Vector Quantization Encoder/Decoder

2.2Tree Vector Extraction-The encoder performs wavelet-based vector quantization on the original signal to generate the encoded signal. After n level wavelet decomposition, before sending the coefficients to the vector quantizer, they have to be converted to a matrix of vectors, where each vector is having a hierarchical structure. Given the n+1 subbands, 'm' tree vectors (Xtv,j) are extracted, where each TV is composed of coefficients taken from these subbands in a hierarchical tree order as shown in Fig 2. For the first TV, $X_{TV,0}$, the first two coefficient pairs from $X_{L.n}$ and $X_{H,n}$, respectively, are assigned to the top and the second layer of the TV respectively. Then, the first two and the first four coefficient pairs from $X_{H,n-1}$ and $X_{H,n-2}$, respectively, are assigned to the third and the fourth layer of the TV and so on. This completes the formation of $x_{TV,1}$. For $X_{TV,1}$, the second coefficient pair from $X_{L,n}$, is assigned to the top layer of the TV. Thus the vector dimension k of a TV is 2^{n+1}.Thus m, the number of TVs for an M-sample long EMG signal, is given by $M/2^{n+1}$. In general, the j^{th} TV can be obtained as follows:

$$X_{TV,j}[1] = X_{L,n}[2*j - 1]$$

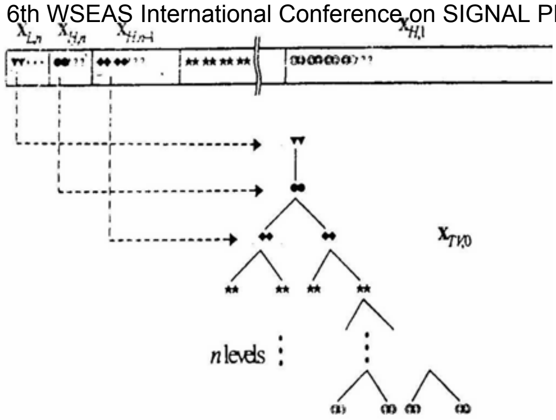

Fig 2: The hierarchical structure of TV

$X_{TV,j}$ [2] = $X_{L,n}$ [2*j]

$X_{TV,j}[2^l+k] = X_{H,n-l+1}[(2^l).j + k - (2^l)]$

j = 1…….m; l = 1……..n; k = 1…….2^l

Where the number in brackets represents the component index of the tree vector[11]. For 1024 samples and 5 level decomposition, 16 tree vector are obtained i.e. from $X_{TV,0}$ to $X_{TV,15}$ .The code vectors in the VQ codebook is based on the structure of TVs created.

2.3VectorQuantization-Vector quantization is a powerful source coding technique as quantizing a set of samples (vector) is more efficient than quantizing a sample (scalar) individually. A codebook plays an important role in VQ, which consists of collection of codevectors. A codebook is created using a codebook-training algorithm by Linde, Buzo and Gray (LBG)[11, 12]. A set of EMG training vectors is used to generate the codebook.

2.3.1.DCCR mechanism of vector quantization-In the DCCR mechanism, the input vector or its approximation is transmitted or stored as a new code vector when the distortion between X_{TV} and $C_{TV,i*}$ is beyond some distortion threshold. Since input Tree vector X_{TV} consists of DWT coefficients with great magnitude differences, it is not efficient to assign a fixed number of bits to every coefficient. Even if we assign different numbers of bits to DWT coefficients according to their magnitudes, the coding efficiency may still be poor because of the varying characteristics of various EMG signals. Therefore, a dynamic bit allocation scheme is used to have better coding efficiency. SPIHT coding strategy not only performs dynamic bit allocation efficiently according to the magnitudes of wavelet coefficients, but also sends or stores encoded data progressively and can be stopped at the point when the distortion falls within the predefined d_{th}. Therefore, a DCCR mechanism is used similar to SPIHT coding strategy and given as follows.

1. If d $(X_{TV}, C_{TV, i*}) \leq d_{th}$, the index i* and a bit "1" are transmitted or stored. The C_{i*} is promoted to the first position of Codebook and all the code vectors in front of it, i.e., $c_0 \sim c_{i*-1}$, are pushed down by one position.
2. If d $(X_{TV}, C_{TV, i*}) > d_{th}$, the index i* and a bit "0" are transmitted or stored. In this case, X_{TV} or its approximation is treated as a new code vector and is inserted to the first position of the codebook, all the original code vectors are pushed down by one notch and the last one is discarded. Then components of the difference vector $e_{TV} = X_{TV} - C_{TV, i*}$ are scalar quantized to obtain e_{TV}. This coding process continues until d $(X_{TV}, C_{TV, i*}) < d_{th}$ .Finally, a 7 bit header is transmitted or stored followed by bit representation of i* and the bit "0". The length 7 is selected here because it is sufficient for the biomedical data under consideration.

Inverse vector quantization is performed on the encoded signal to obtain the approximated set of vectors. A copy of the codebook on the encoder side is used here for decoding purpose. A table look up in the codebook is done to find the code vector corresponding to the index value transmitted in the encoded signal. The inverse of the 'Tree Vector Extraction' process is applied on the vectors to get the DWT coefficients. The DWT coefficients are obtained from all the vectors and arranged to form the sub bands. They are actually arranged in the order as they were arranged on the encoder side[5, 13].

3. Results and analysis

Two analysis measures were used to measure the quality of reconstructed signal.1) **Percentage Root Mean Square Difference (PRD) -**This is a distortion measure and is used to check the objective quality of the reconstructed signal and is given by:

$$PRD = \left\{ \sum_{i=1}^{L} (x_i - x^{\wedge}_i)^2 \Big/ \sum_{i=1}^{L} x_i^{\,2} \right\}^{1/2} \times 100\%$$

Where x_i: original signal samples and $x^{\wedge}_i$: reconstructed signal samples. PRD should be as small as possible so that a good quality of the reconstructed signal is obtained. PRD values below 10% are acceptable. 2) **Compression ratio (CR)** which is the ratio of the original file size to the compressed file size[14].

EMG records each 200ms long were obtained from Dept. of Neurology PGI , Chandigarh and tests were performed for EMG signal compression using DWT-based Vector quantization .To demonstrate the coding performance, large amount of test data is used. The sampling rate was chosen as 360 samples/sec and resolution 11 bits. One set of EMG samples, consisted of 1500 - 1600 samples. Five sets of EMG signals considered are: S3, S5, S6, S8, and S10. Results were obtained by varying different coding parameters such as decomposition level (n), wavelets, Codebook Size (N) and vector dimension (K). Analysis and inferences were drawn on the basis of results obtained.

3.1 Decomposition Level- Tests have shown that the decomposition level 3 gives a lower PRD if small codebook size (2^7, 2^8, 2^9) is chosen. If a higher codebook size (2^{10}, 2^{11}...) is considered, then level 5 shows better results. As the PRD obtained is below 10 for lower codebook size, DWT level 3 is considered appropriate and is used later on for all the tests. Lower codebook size is preferred because it leads to better compression as less number of bits is used to store the index (of the code vectors) in the encoded signal.

3.2Wavelets

Out of all the wavelets chosen, the Daubechies (db1) has shown best results; therefore it has been used for all the tests.

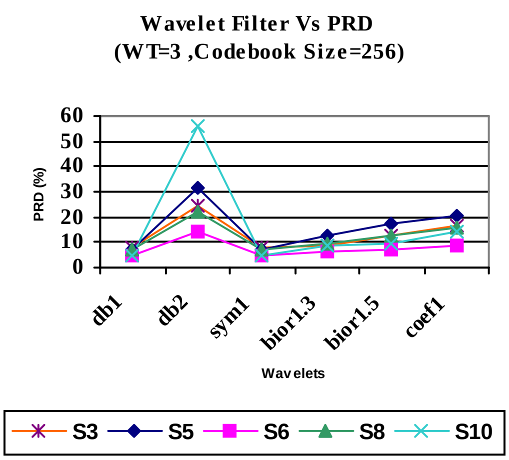

Fig3: PRD for different Wavelets for various EMG signals

us Fig3 clearly shows that for all the signals, the PRD value is minimum for db1 and highest for db2. Sym1 (Symlet1) also shows behavior similar to db1.

3.3.3 Vector Dimension (K)

TThe vector dimension (K) is the size of each input vector created by 'Tree Vector Extraction' process, and is dependent on the decomposition level (n). As n is increased, the vector dimension also increases. For decomposition level 5, vector dimension is 64. The dimension of each code vector in the codebook is dependent on the input vector dimension. Given the vector dimension or decomposition level (n), several codebook sizes were considered to generate the codebook. Hence, a larger codebook is to be used which increases the computational complexity of VQ as well as the size of the encoded signal.

3.4 Codebook Size (N) -Codebook size refers to the total number of code vectors in the codebook. As the size of codebook increases, the quality of the reconstructed signal improves, but the compression ratio reduces and the computational complexity increases. Tests have shown that PRD of the signal reduces with the increase in the codebook size. This is because higher codebook size means more number of codevectors to represent the input signal. This will in turn reduce the compression ratio, as the size of the index (number of bits required to store index of codevectors). Moreover, computational complexity for larger codebook size is also more. Therefore, there is a tradeoff between the quality of the reconstructed signal and the amount of compression achieved. Thus, with a specified vector dimension (K) and codebook size (N), a codebook is generated using LBG algorithm. Fig 5 shows how PRD of various EMG signals decrease with the increase in the codebook size

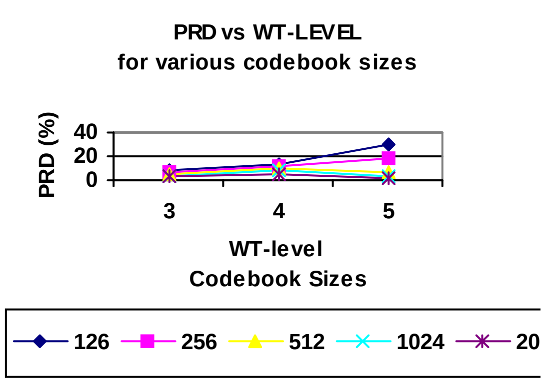

Fig4: Average PRD at different wavelet levels And various codebook sizes.

3.5 Compression ratio Vs Quality (PRD)

TTests have shown that as the compression ratio increases, the PRD of the signal also increases i.e. quality of reconstructed signal decreases. Better compression ratio is obtained for smaller codebook sizes, as less number of bits is required to store the index of the codevector. Since 8 bits are used to store the index of the codevector in the encoded file for codebook size 256 (2^8) and below and 16 bits for codebook sizes 512 (2^9) and above therefore an

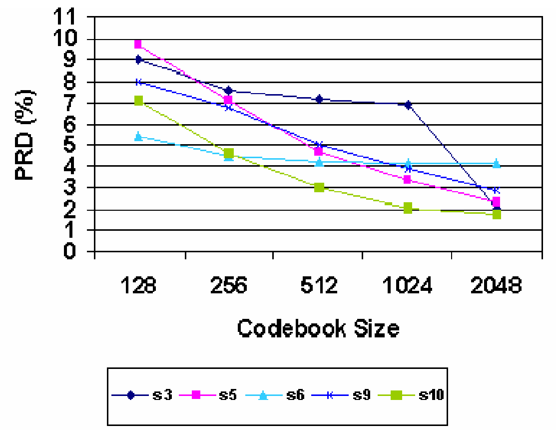

Fig 5: Variation of PRD with the increase in the codebook size for different EMG signals (using WT level:3)

average CR of 20.64:1 at an average PRD of 6.12% is achieved for codebook size 256 (2^8) or below and CR of 15.82:1 is obtained for codebook sizes 512 (2^9) and above as shown in fig 6. Average PRD of 4.62% and CR of 15.70 is obtained for codebook sizes 512 and above.

4. Conclusion

This technique gives a good objective (visual) and subjective quality of the reconstructed signal along with sufficient compression as shown in fig7. Vector Quantization is computational complex due to the large size of the codebook. A good training procedure is required for the codebook generation, so that the codebook is able to encode a wide variety of EMG signals. If the test signal is entirely

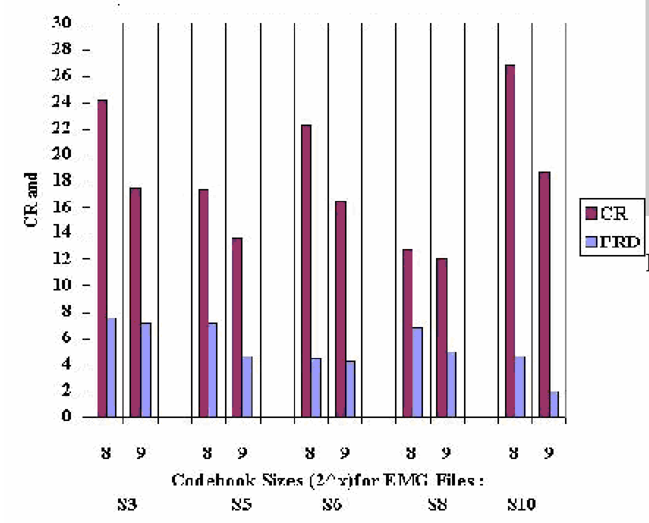

Fig 6: Relation of CR and PRD with the increase in the codebook size from 256(2^8) to 512(2^9). (using WT level:3)

different from the training vectors, the codebook will have to be updated so that it can represent the test signal accurately. Offline Codebook updating is done using Distortion Constrained Codebook Replenishment (DCCR) technique but online codebook updating may be done if on line data is available[13]. The online codebook replenishment feature allows the contents of a codebook to be updated on-line such that the vector quantizer can adapt it to match the input vector.

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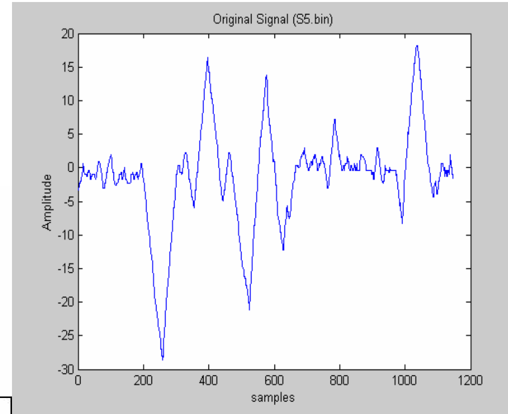

Fig7 - Original Signal (S5.bin) PRD(3.3064%)

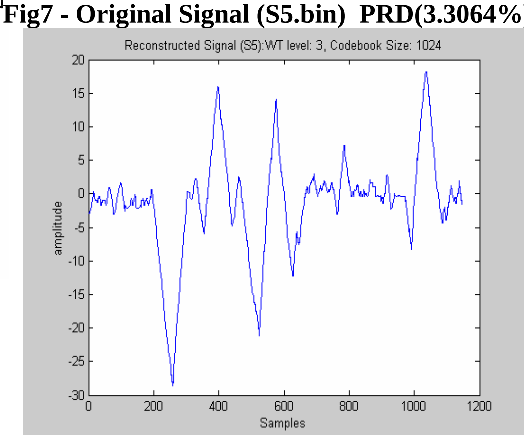

Fig8- Reconstructed Signal :(Codebook size: 1024)

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