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Wavelet based Signal Processing for Compression a Methodology for on-line Tele Cardiology

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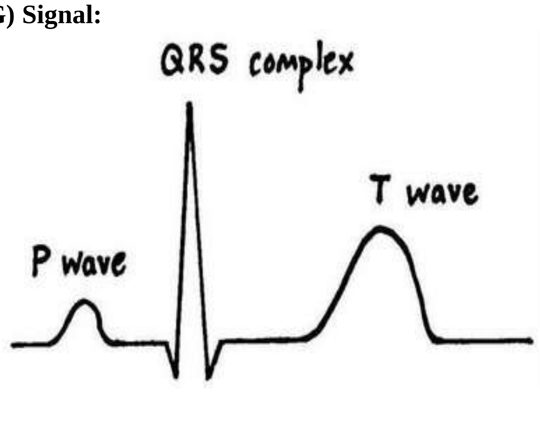
Abstract: *On-Line continuous monitoring of ECG signals and Digital Signal Processing(DSP) for Deviation Detection has specific diagnostic value. Such analysis, need conservation of Digital storage space as large amount of digitized data results from body area electronics. So, Compression becomes essential for such Tele Cardiology, runs into hours and days in the case of critical patients and ICU situation. In this work a methodology for wavelet based on line compression is evolved, segmenting ECG beat waveform into 128 cubic splines, for Digital Signal Processing (DSP). In the compression methodology, depending on sampling rate, of ADC converter of the ECG body area electronics, a 'Δx' parameter is fine tuned practically, to reduce the digital storage space, to be able to do high frequency loss less decompression, from stored digital data, in case of requirement for later usage and analysis or diagnostics. Zonal based coding is also introduced for fine tuning Δ_P, Δ_{QRS}, Δ_T practically, to retain significant diagnostic spectrum in the major waves of ECG beat, for leaving scope, also for future diagnostics. A Basis matrix and function has been fixed for the Digital Signal Processing for compression based on wavelets. Compression to the tune of more than 200% is possible with the methodology, specifically useful for on-line mobile acquisition of digitized ECG, for early ECG deviation detection and tele transfer for diagnostics, in the case of ICU patient or already diagnosed cardiac patient.*
Keywords: *Tele cardiology, ECG, DSP, Wavelets, Compression, Cubic Splines,*

I. Introduction:

One time ECG recording for a few beats may not give sufficient early clues in knowing deviations in the ECG waveform, to associate deviations to different Cardiology ailments. The signal processing based trend has been setting with improved Biomedical signal instrumentation and acquisition precision. The moment, Biomedical signal acquisition is required for long duration, data compression need to be adopted, in recording any such Biomedical electrical signal. Ideally, this Biomedical signal acquisition system need to be equipped with sufficient channels to be able to accommodate, acquisition of large number of Biomedical signals. In this work ECG signal originated from Electrophysiology of heat as shown in Fig 1, below is taken up for compressing it for Tele Cardiology. Any compressed Biomedical signal has specific advantage in Tele medicine and economically attractive, for healthcare delivery, especially in rural and impoverished areas. On these continuously acquired ECG waveforms through Telemedicine, diagnostic software algorithms would evolve and pave way to researchers, to fix various heart abnormalities to fine deviations, detected using wavelet processing of ECG Waveforms.

Electro Cardiogram (ECG) Signal:



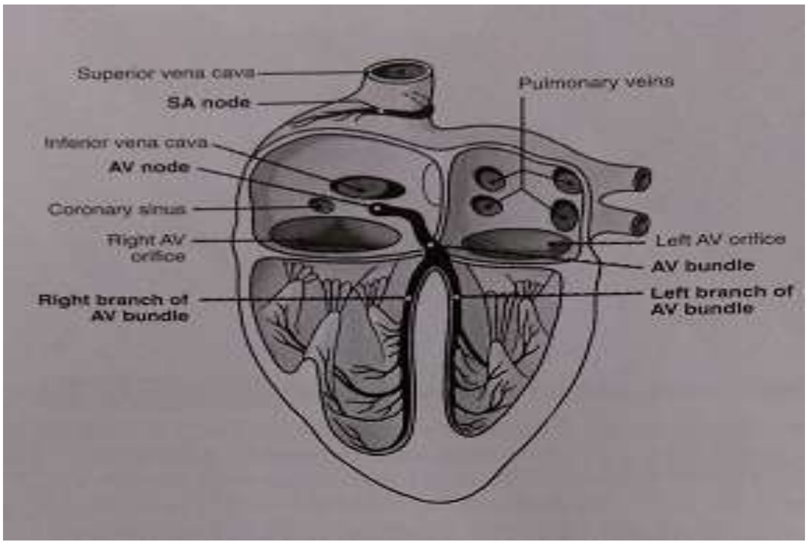


Figure 1. Basic Electrophysiology of the heart and the major waves of a single normal ECG pattern

These continuously recorded Electro Cardiogram (ECG) signals can be used extensively in diagnostic and monitoring real time health of the heart, specifically in Intensive Care Units (ICUs). Keeping a continuous record of ECG of critical patients has specific diagnostic and healthcare advantage. In the range of Biomedical signals, ECG recordings can be safely, sampled at frequencies of the order 2 Khz, without loosing the high frequency component of the wave. Even at these lowest sampling rates, ECG compression is desirable, since an average day of ECG recording typically requires the order of 200 Megabytes of digital storage space. But, when ECG signals or any Biomedical signal has to be processed for critical symptoms for diagnostic value, it becomes, essential to compress ECG, for conserving digital storage space.

In the ECG Tele Recording, the following, subsystems are required to be present in general

- Raw ECG signal I/F receiving with preliminary filtering.
- Digitization with a 'Δ' parameter.
- Digital ECG transmission/reception
- Digital ECG reading/replay
- ECG Normalization and Scaling
- ECG Compression.

One of the earlier work, on ECG Analysis for Deviation Detection is published [19] by the first author, now in the present work ECG signal compression is attempted, specifically with respect to, further Wavelet Processing of ECG signals, in the high spectral regions for deviation detection.

II. ECG Compression Using Cubic Spline Interpolation:

A Cubic Spline Interpolation gives advantage in not leaving any high frequency component, paving way to researchers, for future intensive zonal analysis, associating waveform deviations for various heart ailments. Also, as no single standard polynomial can represent a dynamically varying waveform like Electro Cardio Gram (ECG) completely, the natural choice is to segment the waveform into large number of splines and represent these cubic spline segments with Wavelet Coefficient matrices, corresponding to each cubic spline, forming Basis Matrix or function.

The goal of any cubic spline interpolation[19] is to get an interpolation formula that is continuous in both the first and second derivatives, both within the intervals and at the interpolating nodes, taking input points such as points in a complex plane, as originated from Analog to Digital Converter (ADC) of ECG hardware or body area electronics [3]. Splines tend to be stabler than fitting a polynomial through the N+1 points, with less possibility of wild oscillations between the tabulated points. Higher the order of the spline, better would be the true representative equation of the dynamically varying incoming bio-medical waveform, generated due to the polarization and depolarization of the myocardium tissue and the associated conduction changes.

III. Segmentation And Formation Of Wavelets:

A cubic curve or spline could be defined as

$$x(t) = a_3 t^3 + a_2 t^2 + a_1 t + a_0$$

In the matrix form the equation can also be written as

$$x(t) = T . A$$

for representing any time series.

To sense signal strength, our choice in this specific Digital Signal Processing of ECG waveform, the coefficients will be in complex plane in the time series.

$x(t) = T.A$ can be written as

$$x(t) = [\, t^3 \; t^2 \; t \;\; 1 \,] \times \begin{bmatrix} a_3 \\ a_2 \\ a_1 \\ a_0 \end{bmatrix}$$

The derivative of this curve w.r.t 't' can be expressed as

$$dx/dt = [\, 3t^2 \;\; 2t \;\; 1 \;\; 0 \,] \times \begin{bmatrix} a_3 \\ a_2 \\ a_1 \\ a_0 \end{bmatrix}$$

Now, we can find wavelet values at the beginning and end of the wavelet and the slope of the wavelet and the middle point on the time axis from the above derivative of the matrix equation.

By substituting t = 0, 0.5 and 1 at the respective points in the above direct and derivative matrix spline representations, we get

$$x(0) = [\,0\;0\;0\;1\,]\,[\,A\,]$$

$$x(0.5) = [\,0.5^3\; 0.5^2\; 0.5^1\; 0.5^0\,]\,[\,A\,]$$

$$x^{`}(0.5) = [\,3\,(0.5^2)\;\; 2(0.5)\;\; 1\;\; 0\,]\,[\,A\,]$$

$$x(1) = [\,1\;1\;1\;1\,]\,[\,A\,]$$

OR

$G_x = B * A$ Where

$$G_x = \begin{bmatrix} X_0 \\ X_{0.5} \\ X`_{0.5} \\ X_1 \end{bmatrix}$$

$$B = \begin{matrix} 0 & 0 & 0 & 1 \\ 0.125 & 0.25 & 0.5 & 1 \\ 0.75 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{matrix}$$

Now, solve for ‘A’ the coefficient matrix using the matrix inverse equation

$$A = B^{-1} G_x \quad \text{--------} \quad 1$$

The G_x matrix having complex elements corresponding to any Wavelet is formed taking ‘5’ points in the incoming time series .

The B^{-1} the Basis Matrix of the Spline from the above B Matrix is

$$B^{-1} = \begin{matrix} -4 & 0 & -4 & 4 \\ 8 & -4 & 6 & -4 \\ -5 & 4 & -2 & 1 \\ 1 & 0 & 0 & 0 \end{matrix}$$

At a sampling rate of 2048 bytes/ second, about 410 Cubic Spline equations are formulated for this ECG Digital Signal Processing.

Effectively the ECG Waveform is formulated into Wavelet Coefficient Matrix array of the form for storage

$$\begin{bmatrix} A_{11} & A_{12} & A_{13} & \text{----} & A_{1\,100} \\ A_{21} & A_{22} & A_{23} & \text{----} & A_{2\,200} \\ | & | & & & | \\ | & | & & & | \\ A_{41} & A_{42} & A_{43} & \text{-------} & A_{4\,400} \end{bmatrix}$$

Where ‘A’ s are individual matrices having complex elements computed from the matrix equation ‘1’ above.

IV. Compression Methodology:

The Wavelet transform techniques for ECG data compression have received a great deal of attention, over the past several years [5] - [10], in the frequency domain. Non of these techniques have captured enough high frequency components, required for better diagnostic value. So, wavelet compression technique is examined, taking complete representation of ECG with spline wavelets, for practical implementation in Tele Cardiology application and further ECG waveform processing for abnormalities and deviations.

Approximately, there are 400 vectors having complex numbers, that represent each ECG beat. Corresponding to ‘Δ’ of the ADC in the body area electronics, a ‘Δx’ parameter is arrived at, depending on the high frequency loss tolerance, for a specific heart ailment analysis based on the ECG deviation. This ‘Δx’ parameter could be change in slope at the middle point of the spline, with respect to the slope at the middle point of the preceding spline, which determines, whether to include or discard the vector corresponding to the spline, for saving digital storage space. It is either storing the included vector or ‘Δx’ corresponding to the excluded vector, for reconstructing the wavelet, in case of requirement or decompression. Each vector will have four wavelet coefficients. The wavelet matrix is of the size of 400 vector arrays in it’s uncompressed form. Each of the excluded vector with the support of practically fine tuned ‘Δx’ threshold, from ‘$\Delta x_{maximum}$’ and ‘$\Delta x_{minimum}$’ values, for a specific sampling rate is replaced with the difference in slopes of successive splines. Thus the matrix array size is reduced eliminating the insignificant vectors. In this method a minimum compression of 200% is achievable, for Tele Cardiology.

V. Zonal Based Wavelet Compression:

In any wavelet transform, there exist some fixed zones of special vectors that need to be subjected to minimum compression, in order not to loose, information required in the wavelet. So, zones are practically fine tuned, to apply variable ‘Δx’ along the ECG waveform, by simply increasing or decreasing the sizes of the fixed selected zones of the spectral vector and the transmitted clinical ECG data. Such a methodology provides, minimized memory and less digital signal processing cycles with a more computationally efficient technique with simpler, programmable concept for enhancing the performance of the hybrid Tele Cardiology system.

Description:

Over the period zonal coding based wavelet method is developed for discrete " Lipschitzian "signals [11] in frequency spectrum. The associated derivations are discussed in [11]-[13].

The following is the general representation of ECG in wavelet matrix form for utilizing in ECG compression.

$$\mathbf{W.X = Y}$$

or

$$\begin{pmatrix} \omega_{1,1} \text{ ------------- } \omega_{1,N} \\ \text{--------------------------------} \\ \text{--------------------------------} \\ \text{--------------------------------} \\ \text{--------------------------------} \\ \omega_{N,1} \text{ ------------- } \omega_{N,N} \end{pmatrix} * \begin{pmatrix} X_1 \\ | \\ X_N \end{pmatrix} = \begin{pmatrix} Y_1 \\ | \\ Y_N \end{pmatrix}$$

Where 'X' is the raw ECG signal column vector and 'y' is the transform coefficient vector.

In order to apply compression methodology, to the samples of a segmented ECG signal, all the successive differences between slopes at the middle point of the spline segment must be calculated and the maximum and minimum of these differences are computed over a ECG beat and a 'Δx' parameter can be practically fine tuned, which has to be much higher than the 'Δ' of Σ to Δ Analog to Digital Converter (ADC) at the digitisation front end stage of body area electronics.

In the case of a given 'N" dimensional wavelet transform, the corresponding N X N wavelet matrix, i.e the transform matrix which, if applied to the input signal, produces all wavelet coefficients, is generated next.

A wavelet matrix can be chosen typically, which represent the best range of different smoothness and symmetrical parametric features of a spline mother wavelet. Then, zonal marks are selected for the wavelet physical and spectral zones 'P', 'QRS','T', of ECG which have higher maximum values, fixing a size of the zonal mark. Corresponding to these zones, $\Delta_{P,}$ $\Delta_{QRS,}$ Δ_T, parameters are practically fine tuned, using the 'Δx' setting, procedure mentioned, in the para above.

The wavelet transform is then applied to the 400 ECG sample vectors and the compression is achieved by discarding vectors to be eliminated, based on, slope differences 'Δ_P', 'Δ_{QRS}', 'Δ_T' thresholding in the respective ECG wave form regions and transmitting, only those coefficients, that are not discarded, for digital storage, for further analysis and decompression as and when required.

VI. Conclusion

The above compression becomes, essential for Tele Cardiology for further processing of Electro Cardiogram for various analysis to detect abnormalities and decompress without loss of spectral frequencies, as and when required. Approximately, there can be a saving of more than 200% in time in transmission and may result a compression of the order of 200% for ECG recordings of Tele Cardiology.

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