ECG Signal Compression by Predictive Coding and Set Partitioning in Hierarchical Trees (SPIHT)

Grafika Jati*, Aprinaldi*, Sani M.Isa†, Wisnu Jatmiko*
*Faculty of Computer Science, Universitas Indonesia - Depok
†Magister Teknologi Informasi, Bina Nusantara University
Email: grafika.jati51@ui.ac.id, aprinaldi31@ui.ac.id

***Abstract*—In this paper we present a method for multi-lead ECG signal compression using Predictive Coding combined with Set Partitioning In Hierarchical Trees (SPIHT).We utilize linear prediction between the beats to exploit the high correlation among those beats. This method can optimize the redundancy between adjacent samples and adjacent beats. Predictive coding is the next step after beat reordering step. The purpose of using predictive coding is to minimize amplitude variance of 2D ECG array so the compression error can be minimize . The experiments from selected records from MIT-BIH arrhythmia database shows that the proposed method is more efficient for ECG signal compression compared with original SPIHT and relatively have lower distortion with the same compression ratios compared to the other wavelet transformation techniques.**

Keywords: Predictive Coding, Electrocardiogram, Compression, wavelet transform, SPIHT

I. INTRODUCTION

Heart disease or cardiovascular disease is the number one cause of death globally according WHO data. Heart disease is a term for various kinds of errors caused by cardiac disfunction. The risk of heart disease can be reduced by regular controls on the performance of the heart, and it can be monitored and analyzed by medical personnel to get proper treatment. Electrocardiogram (ECG) is a test for the electrical activity of the cardiac muscles of the heart. The pattern in the ECG signal can be used to identify specific order of electrical activities on every heartbeat. Doctor or a qualified professional can identify if there any problem with damaged cardiac muscles by monitoring the pattern on the ECG signal because some of cardiac disorders can be visually identified from the pattern on the ECG signal. To make an accurate estimation, Cardiovascular Specialist Doctors need to observe the multi-lead ECG signals from patient. The problem is the volume of multi-lead ECG data produced by recoding or monitoring system can be reasonably large over long monitoring period. For example, 24 hours recording of 12-leads ECG signals with 256 Hz sampling rate, and 11bit/sample data resolution requires about 396 Mbytes of storage. Therefore, it needs a large number of time, storage, and bandwidth to be used and it must be compressed during transmission process, so the research about ECG signals compression becomes an important issue in biomedical engineering and signal processing. Because of exponential growth experienced by telemedicine, the needs for storage and efficient transmission of medical information such as ECG signals to be increased more than a decade.

Electrocardiogram signals can be seen like an image that contain redundant information. One of the aim of compression is to minimize the size or the shape of the ECG signal and also eliminate the redundancy. The compression method is very important to be done since we need technology to transmit the signal for early disease detection to support limitation of Cardiovascular Specialist Doctors, so that it is crucial to build a system that records heart from distance or Tele-Electrocardiograph.

Tele-Electrocardiography signal is technology that record electrocardiogram (ECG) signals and transmit it. In medical area, record of medical information is required to produce an accurate ECG, so the recording from multi-lead ECG in a few days continuously make the data quite large. If we are talking about accuracy, research in field of ECG signals for arrhytmia beat classification like wisnu et.al work [1] is not our concern in this paper. Therefore, beside the classifier accuracy, we also have to compress the data because there is a need of smaller data size to transmitted over communication networks.

Research in ECG signals compression is a widely discussed topic in biomedical engineering. Previous research by Isa et al propose ECG Signal compression using SPIHT with beat reordering for optimization [2]. Another approach by Linnenbank et al proposed Huffman Code for ECG signal compression [3]. For SPIHT it self, there are several modification proposed by some researchers, such as: Lu et al propose 1D SPIHT compression for single and multi-lead signals [4]; Goudarzi et al propose an ECG compression algorithm based on two dimensional (2-D) multi wavelet transforms [5]; application on lifting wavelet transform and adopted different threshold value for high frequency sub-band in SPIHT coding is method proposed by Wang et al. [6]; Sharifahmadian present enhanced SPIHT coding that limits redundant evaluation in the sorting pass of SPIHT for single and two leads ECG signal compression [7]; Nayebi et al. proposed run length coding (RLC) on SPIHT for minimizing the length of bit stream. Same with Goudarzi, Nayebi used similar 2D ECG array as an input for SPIHT coding [8]; and Shahraeian and Fatemizadeh applied vector quantization on residual image obtained from SPIHT coding [9].

To optimize the compression of ECG signals, in this paper we propose a improvement of compression algorithms by adding a new technique to change signal data. Technique that we used in this proposed method is predictive coding which

 978-1-5090-0363-1/15/$31.00

is a simple method for reduction of intra-beat, and inter-beat redundancies on the multi-lead ECG signal, this technique adapted from Differential Pulse Code Modulation (DPCM) algorithm. This coding method predict the sample values of a signal based on previous values, and coding the prediction error. To predict the current sample value, the method calculate the difference between the actual sample value and its predicted value. Jun Wang et. al also use spectral DPCM to prediction error image and adaptive bit-level arithmetic coding to differential coefficients to Hyper-spectral image lossless compressing based on spectral DPCM [10], based on the fact that most source signals show signicant correlation implies lower bit rate. Furthermore, in this paper we use predictive coding to optimize to ECG signals lossless compression.

In section 2, the background method that used in this proposed method will be described. Basic concept of Predictive Coding and Set Partitioning and Hierarchical Trees (SPIHT) will be provided. Design of proposed method is described in Section 3. Experiments results are presented in Section 4, and also the conclusion and further discussion as open problem of this paper are briey discussed in the last section of the manuscript.

II. Background

The objective of this research is removing the redundancy in multi-lead ECG signals. In the fact that the characteristic of ECG signals is full of redundancy, which means there are dependency between adjacent samples of the signal. ECG signal basically consist of P, Q, R, S, and T wave as a feature, and many of beat cycles have similar basic signal shape. By knowing the redundancy of the signal, we can know that there is a possibility to predict next samples of ECG signal since we already know the basic form of each beat cycle.

A. Predictive Coding

In recent years predictive coding has become a popular data compression technique. To improve compression performance over independent coding, predictive coding exploits the correlation in spatial or temporal dimensions, or context [11]. Differential Pulse Code Modulation (DPCM) as one of predictive coding example used in several researches to improve performance over standard PCM. DPCM usually used in MPEG video coding because by using DPCM can significantly improve compression ratios over independent coding of video frames. In [12], Wang et. al. used predictive coding to compress hyper spectral images, because those images have strong local correlations. A general block diagram of a DPCM encoder and decoder can be seen in Fig. 1 .

B. Set Partitioning in Hierarchical Trees (SPIHT)

SPIHT is Wavelet based image coding proposed by Said and Pearlman in 1996. This method is widely used in the field of image compression than other techniques because of its high compression efficiency [13]. Since introduced in 1996, SPIHT is still used for image compression and has received a lot of attention, it is because SPIHT is simpler and more efficient

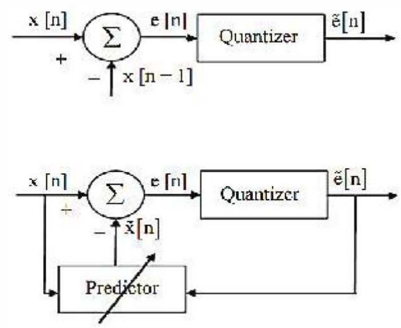

Fig. 1. General block diagram of a predictive coding

than many existing compression method. And since 1996 there are a lot of improvement and modification of SPIHT in several approach like speed, redundancy, quality, error resilience, complexity, memory requirement and compression ratio [14].

SPIHT is a compression method that was developed from the EZW (Embedded Zero Tree) method [13]. The SPIHT coding is an wavelet-based technique based on construction of coefficient trees and successive approximations that can be implemented as bit plane processing.

C. Previous Work in ECG Signal Compression

There are a lot of previous research on ECG Signal Compression. Isa at. al. use 3D SPIHT to compress ECG Multilead signal [15]. In that paper, 3D SPIHT optimized with beat reordering and residual calculation. In his result show us the analysis the effect of beat ordering and residual calculation to overall compression performance. Beat reordering combined with residual calculation can improve the compression performance, it can be seen in the PRD and CR evaluation. Jati et.al also implement 2D Set Partitioning In Hierarchical Tree (SPIHT) On Embedded Devices For Multilead ECG Signal Compression [17], the implementation in embedded device aim to make compression process faster.

III. Methodology

The main pipeline of the proposed method devided into two part, the first is compression and the second is decompression. The schematic diagram of compression and decompression stage of the proposed method is shown in Fig. 2 and Fig. 6.

A. Prepocessing

The compression process start with pre-processing process. The pre-processing process consist of baseline wonder removal, beat detection, and beat normalization.

- Base Wonder Removal
  This method proposed by Sargolzaei to remove baseline wander from ECG signal [18]. Baseline wander is a common phenomenon in biomedical electric recording such as ECG. By removing baseline wander we can enhance ECG signal characteristics for clinical diagnoses,

 978-1-5090-0363-1/15/$31.00

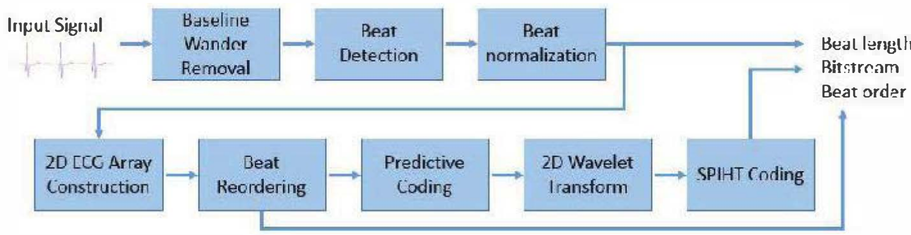

Fig. 2. Compression stage

so that BWR is essential to be done in pre-processing stage.

- Beat Detection
  This stage determines the beat of clean signals which is represented by the R-wave on the ECG by using QRS detection algorithm. The algorithms use low pass filtering stage, followed by the high pass filtering to perform a bandpass filter on the input signal. The aim of this stage is to reduce the noise of ECG signals.
- Beat Normalization
  In this stage, the duration or number of sample for each beat will be standardized. The duration of each beat normalized using multirate approach and targeting certain number of samples, in our system each beat has 128 samples.

B. 2D ECG Array Construction

Something that will be done in this stage is arrangement heart beat signal in 2D array representation. The main objective of this stage is to get the regularity properties of the ECG signal. According Mamaghanian [19], an ECG signal has pseudo-periodic signals so that each heartbeat cycle always repeats the same pattern, namely P-QRS-T. A generated 2D array of ECG signal has a high degree of regularity because every row matrix consists of a vector representing one cycle of the ECG signal, which is mean in one row is consist of one beat heart beat signal. For example, if 2D array of ECG signal has 128 rows, in which each row has 128 samples, we can say the matrix size is of 128×128.

C. Beat Reordering

Beat reordering aim to reorder beat or ECG cycle in 2D ECG array based on their similarities. By rearranging the beat order, similar ECG cycle placed in a close position and it can take advantage of high correlation among the adjacent beats. The higher correlation between adjacent beats make the prediction of the next samples of data easier.Therefore, the higher compression rate is easier to achieve on high predictable data. The reordering technique provided by Isa et. al [2] use fuzzy cmeans clustering to cluster similar beats, and than also rearranging the order of beats inside each cluster based on their distance to the centroid.

D. Proposed Predictive Coding

In this stage, a compression technique based on exploration of the detection of redundancies on the original signal is applied. This technique encode sample of the wave signal with main objective is to reduce the amplitude variation of 2D array ECG signals. The technique makes the signal value that will be processed on the next step for wavelet transform and SPIHT become relatively smaller.

Methods carried out at this stage is to perform reduction in the value of the original signal with a fixed value of a beat that has been chosen to be a benchmark, it can ensure a smaller signal value can minimize variation amplitude ECG variance of the 2D array. Process performed in the algorithm is as follows: Firstly, select a beat that is most representative of a group or a cluster of beats, for the next we call a beat that has been chosen as the benchmark beat. Selection of benchmark beat can be done using several approaches, such as: using the first beat in a cluster that has been ordered, or construct a new benchmark beat with a certain statistical values of all samples from 2d ECG array (min, mean, or max).

After we have a benchmark beat from previous stage, next step is remake a new 2D ECG array by calculating the difference between real sample signal value with benchmark beat value. Illustration of this approach can be seen in Fig. 3.

Fig. 3 shows the illustration of our proposed method. From previous stage we get ordered beat in clustered data, the number of cluster denoted as n. After that, we define a benchmark beat for every single cluster $(C1, C2, ..., Cn)$. The benchmark of every cluster denoted as $BB1, BB2, ..., BBn$. The last step is calculate the new value for each sample in each beat. New sample value in this step denoted as BP, BP is calculated by subtraction of previous sample value from original beat value (BO) with sample value of the corresponding sample value in benchmark beat (BB). The result of this step can reduce the variance of 2D ECG array variation, or in the other hand we can say that the amplitude of the signal is reduced. Fig. 4 shows us the sample of amplitude reduction from ECG signal on predictive coding process.

Furthermore, the process of calculating the difference between a real signal with benchmark signal obtained good results for compression method, according to the lossless behavior of this approach since there is no information loss during the process.

 978-1-5090-0363-1/15/$31.00 ©2015 IEEE

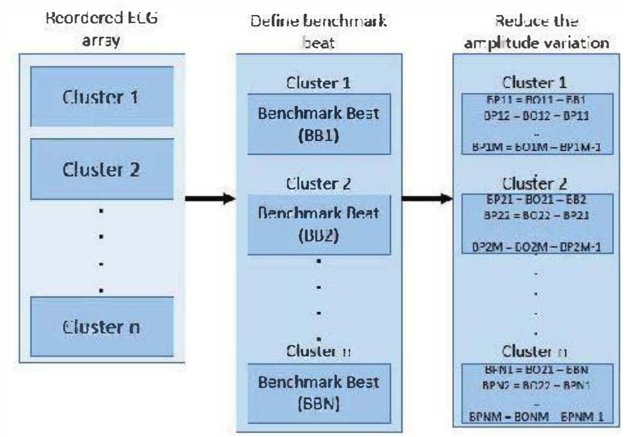

Fig. 3. The illustration of coding technique

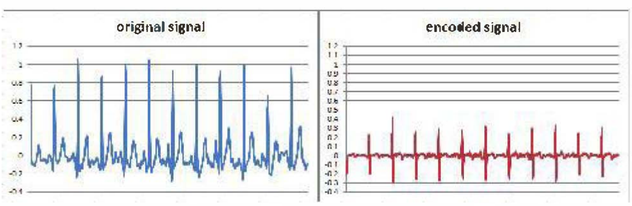

Fig. 4. Sample of amplitude reduction from ECG signal

E. 2D Wavelet Decomposition

The 2D Wavelet Decomposition generates wavelet decomposition from the 2D ECG array that has been formed. Implementation of Wavelet Decomposition using Library 1D/2D Wavelet Transform artificial Rafat Hussain, MIT License and in this research we use the bior 4.4 mother wavelet. The highest decomposition level that can be achieved is level 7 because the matrix size is of 128×128, where $128 = 2^7$. After we get the result from wavelet decomposition, the coefficients are ready to become the input of the 2D SPIHT compression process.

F. 2D SPIHT Compression

Set partitioning in hierarchical trees (SPIHT) is one of the state of the art wavelet-based coding techniques, which orders the transform coefficients using a set partitioning algorithm based on the sub-band pyramid, developed from the EZW (Embedded Zero Tree) method [13]. Fig. 5 shows the spatial orientation tree is represented in the pyramid structure. Wavelet decomposition in principle has the same derivative between subbands. The similarity of the offspring is eventually encoded using SPIHT compression algorithm.

SPIHT coding consists of three main stages, brief SPIHT algorithm described as follows.

1) Setting and Initialization
   firstly setting the coordinates of wavelet coefficients based on spatial orientation tree
   The following set of coordinates used in SPIHT:

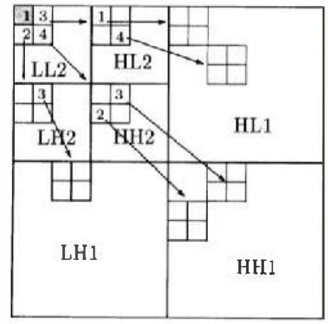

Fig. 5. The Spatial Orientation Tree

   - H : set of coordinates of all root in spatial orientation tree.
   - $O(i,j)$: set of all offspring of a node *(i,j)*
   - $D(i,j)$: set of all descendant of node*(i,j)*
   - $L(i,j)$: *D(i,j) - O(i,j)*

2) Sorting Pass LIP and LIS

   This stage is used to sort the coefficients based on the value of the coefficient. The sorting use threshold that is updated on every process of sorting and refinement. SPIHT requires grouping the coefficients in the three sets, namely:
   a) LIP (list of insignificant pixel) is the coordinates of insignificant coefficients based on the current threshold.
   b) LSP (list of significant pixel) is the coordinates of significant coefficients based on the current threshold.
   c) LIS (list of insignificant sets) is a set of subtress roots coordinates which are insignificant.

   For sorting in LIP, each coefficient in the LIP is checked and the significant coefficients are moved to the LSP. For LIS sets of coefficients is updated if the entry becomes significant then the coordinates of the coefficient is moved to LSP, but If an entry in the LIS is insignificant, a zero is sent.
3) Refinement pass
   Each entry of LSP is checked. If it is significant (under current threshold), a one is sent and its magnitude reduced by the current threshold. Otherwise, a zero is sent.

After compression scheme, the decompression scheme can be seen in Fig. 6. The decompression method used to convert back the compressed signal to the original ECG signal data.

G. Dataset

In this research we use the multi-lead St. Petersburg electrocardiogram (ECG) data from Physionet ATM. The data are already equipped with annotations from one patient. The record consists of 12 lead signals, but in this research only

 978-1-5090-0363-1/15/$31.00 ©2015 IEEE

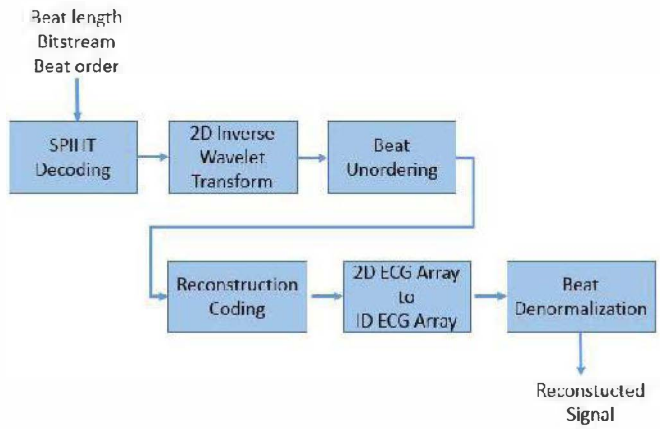

Fig. 6. Decompression stage

used 8 signal leads, namely Lead I, Lead II, Lead V1, Lead V2, V3 Lead, Lead V4, V5 Lead, Lead V6. The signal on each record has a resolution of 12 bits, which is mean that one sample point signal is represented in 12 bits.

H. Evaluation

For the evaluation method we use two parameters here, namely compression ratio(CR) and percentage root-mean-square difference(PRD). Those two parameter will be calculated to measure the performance of a compression method. The first parameter Compression ratio is formulated as follows.

$$CR = \frac{n_{bit\_ori}}{n_{bit\_compressed}} \tag{1}$$

where n_{bit_or} and $n_{bit\_compressed}$ indicate the number of bits in the original signal and the number of bits in the compressed signal, respectively.

The second parameter is PRD, the most used in majority of scientific works, shows the percentage difference between the results of the reconstruction of the original signal with the compressed signal. PRD is measured with the following equation:

$$PRD = \sqrt{\frac{\sum_{n=1}^{N}(x(n)-\hat{x}(n))^2}{\sum_{n=1}^{N}x^2(n)}} \tag{2}$$

where x and $\hat{x}$ indicate the original signal and reconstructed signal, respectively.

IV. Result and Conclusion

In the results section, we want to show the experiment results of our proposed method. We explore the effects of the selection method for choosing the benchmark beat. For each technique, we run the experiment for 3 times and the mean of PRD from this scenario can be seen in Table I.

In table I we can see the comparison result among 4 technique to select the benchmark beat. The result show us no one of those technique gives the best PRD consistently, It's caused by the statistical technique strongly depend on the specific distribution character of the signal. Therefore, no one of those technique can guarantee give the best result. But for comparison purposed in next scenario, we choose the maximum as a technique to select the benchmark beat.

TABLE I. Comparison among Technique to Select Benchmark beat

Method	CR							
	8	10	14	18	22	26	28	30
Proposed (first beat)	1,766	2,244	3,279	3,447	**3,900**	4,610	5,178	5,568
Proposed (mean)	1,978	2,039	3,107	**3,250**	4,180	**4,587**	5,113	**5,136**
Proposed (min)	1,672	2,300	2,986	3,890	4,010	4,663	5,446	6,199
Proposed (max)	**1,625**	**1,842**	**2,945**	3,521	4,299	4,742	**5,043**	5,148

TABLE II. PRD comparison with other method

Method	CR							
	8	10	14	18	22	26	28	30
Moazami et.al	2.12	2.52	3.33	4.20	5.08	5.93	6.34	6.72
our proposed	**1,63**	**1,84**	**2,95**	**3,52**	**4,30**	**4,74**	**5,04**	**5,15**

The second scenario is comparing performance of the proposed method with the 2D multi wavelet transform compression for ECG signal proposed by moazami [5], and we compare it with the same records from MIT-BIH arrhythmia database and also use the same compression rates for this comparison [8, 10, 14, 18, 22, 26, 28, and 30]. The result can be seen in Table II.

In table II we can see the best result from our proposed method (depend on technique to select benchmark beat) better than [5]. The mean PRD of our proposed method at all compression rates are smaller than [5], our hypotheses have been proven. Fig. 7 shows the signal reconstruction almost coincide with the original signal.

In this paper we proposed an ECG signal compression method based on two-dimensional wavelet transform which employs SPIHT coding and beat reordering technique combined with predictive coding. The experiment result shows that the proposed method has better performance compared

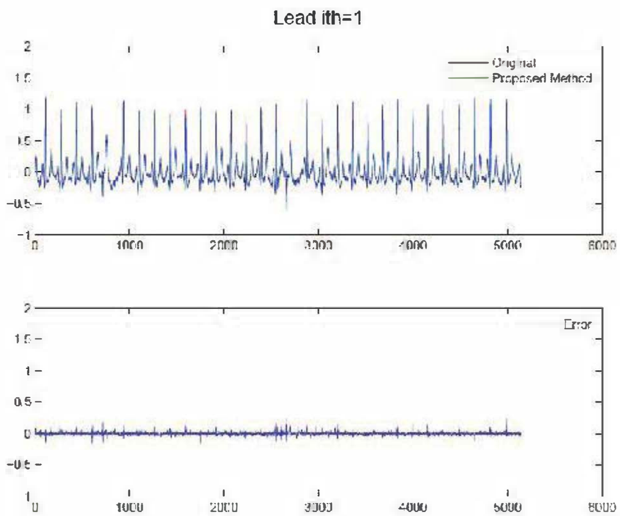

Fig. 7. The Example of Reconstructed Signal Record

with previous ECG signal compression methods. In the future work, the research of optimal configuration and technique of predictive coding will undoubtedly remain a prospect to be used in ECG signal compression, and technique to reorder beat will be tuned for get a better result

V. ACKNOWLEDGEMENT

This work is supported by Grant of National Innovation System Intensive Research No.0478/UN2.R12/HKP.05.00/2015 year 2015-2016 entitled "Smart E-health System For Early Detection Of Heart Disease And Intrauterine Growth Retardation based on 12-Lead ECG and Portable USG device" by the Ministry of Research and Technology, Republic of Indonesia.

REFERENCES

[1] W. Jatmiko, W. P. Nulad, M. I. Elly, I. M. A. Setiawan, and P. Mursanto, "Heart beat classification using wavelet feature based on neural network," *WSEAS Transactions on Systems*, vol. 10, no. 1, pp. 17–26, 2011.

[2] S. M. Isa, W. Jatmiko, and A. M. Arymurthy, "Beat reordering for optimal electrocardiogram signal compression using spiht," in *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, 2012, pp. 226–231.

[3] A. Linnenbank, J. Kemmelings, S. Muilwijk, A. Peper, and C. Grimbergen, "An effective compression scheme for multilead ecg signals containing ectopie ventricular activation," in *Engineering in Medicine and Biology Society, 1992 14th Annual International Conference of the IEEE*, vol. 2, Oct 1992, pp. 527–528.

[4] Z. Lu, D. Y. Kim, and W. Pearlman, "Wavelet compression of ecg signals by the set partitioning in hierarchical trees algorithm," *Biomedical Engineering, IEEE Transactions on*, vol. 47, no. 7, pp. 849–856, July 2000.

[5] M. Moazami-Goudarzi, M. H. Moradi, and S. Abbasabadi, "High performance method for electrocardiogram compression using two dimensional multiwavelet transform," in *2005 IEEE 7th Workshop on Multimedia Signal Processing*, 2006.

[6] S. . Tai, C. . Sun, and W. . Yan, "A 2-d ecg compression method based on wavelet transform and modified spiht," *IEEE Transactions on Biomedical Engineering*, vol. 52, no. 6, 2005.

[7] E. Sharifahmadian, "Wavelet compression of multichannel ecg data by enhanced set partitioning in hierarchical trees algorithm," in *Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings*, 2006, pp. 5238–5243.

[8] S. Nayebi, M. H. Miranbeigi, and A. M. Nasrabadi, "Wavelet based 2-d ecg compression by implementing of spiht algorithm and rl coding," in *ICALIP 2008 - 2008 International Conference on Audio, Language and Image Processing, Proceedings*, 2008, pp. 1349–1353.

[9] S. M. E. Sahraeian and E. Fatemizadeh, "Wavelet-based 2-d ecg data compression method using spiht and vq coding," in *EUROCON 2007 - The International Conference on Computer as a Tool*, 2007, pp. 133–137.

[10] J. Wang, "Hyper-spectral image lossless compressing based on spectral dpcm and intra-dpcm," *Chinese Optics*, vol. 6, no. 6, pp. 863–867, 2013.

[11] A. C. Miguel, A. R. Askew, A. Chang, S. Hauck, R. E. Ladner, and E. A. Riskin, "Reduced complexity wavelet-based predictive coding of hyperspectral images for fpga implementation," in *Data Compression Conference Proceedings*, 2004, pp. 469–478.

[12] H. Wang and K. Sayood, "Lossless predictive compression of hyperspectral images," pp. 35–55, 2006.

[13] A. Said and W. A. Pearlman, "A new, fast, and efficient image codec based on set partitioning in hierarchical trees," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 6, no. 3, pp. 243–250, 1996.

[14] S. B. Chandandeep Kaur, "Improvements of spiht in image compression-survey," *International Journal of Emerging Technology and Advanced Engineering*, vol. 3, pp. 652–656, jan 2013.

[15] S. M. Isa, W. Jatmiko, and A. M. Arymurthy, "3d spiht for multi-lead ecg compression," in *Proceedings - IEEE International Conference on Robotics and Automation*, 2014, pp. 488–493.

[16] ——, "Beat reordering for optimal electrocardiogram signal compression using spiht," in *Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics*, 2012, pp. 226–231.

[17] M. A. M. Grafika Jati and W. Jatmiko, "2d set partitioning in hierarchical tree (spiht) on embedded devices for multilead ecg signal compression," in *International Conference on Physics and Its Applications*, 2014.

[18] A. Sargolzaei, K. Faez, and S. Sargolzaei, "A new robust wavelet based algorithm for baseline wandering cancellation in ecg signals," in *ICSIPA09 - 2009 IEEE International Conference on Signal and Image Processing Applications, Conference Proceedings*, 2009, pp. 33–38.

[19] H. Mamaghanian, N. Khaled, D. Atienza, and P. Vandergheynst, "Compressed sensing for real-time energy-efficient ecg compression on wireless body sensor nodes," *IEEE Transactions on Biomedical Engineering*, vol. 58, no. 9, pp. 2456–2466, 2011.

[20] J. Braams. (2008, Jul.) The babel package. [Online]. Available: http://www.ctan.org/tex-archive/macros/latex/required/babel/