A Proposed Technique Based on Wavelet Transform for Electrocardiogram Signal Compression

Article · April 2019

2 authors:

Saif Addin Rubaee
University of Anbar

Azmi Shawkat
University of Anbar

A Proposed Technique Based on Wavelet Transform for Electrocardiogram Signal Compression

Azmi Shawkat Abdulbaqi
College of Computer and Info. Tech.
IRAQ ,University of Anbar
azmi_msc@yahoo.com

Saif Al- din M. Najim
College of Computer and Info. Tech.
IRAQ ,University of Anbar
Sayf73@gmail.com

Falath M. Mohammad
College of Computer and Info. Tech.
IRAQ ,University of Anbar
falath.mansour@yahoo.com

Nawar Ahmed Irsan
College of Computer and Info. Tech.
IRAQ ,University of Anbar
nawar_aljumaily@yahoo.com

***Abstract*— An electrocardiogram (ECG) is an electrical record of heart activity. ECG compression is the biggest concern for many applications in the biomedical community. ECG lossless compression (ECG LC) is data recovery for diagnostic and analysis purposes. The aim here develops an efficient algorithm ECG LC. This algorithm uses the transform based on wavelet followed by the arithmetic coding (AC) on the residual. The parameters of performance measurement for the ECG signal such as CR (Compression Ratio), PRD (Percent Root mean square Distortion). The proposed algorithm achieves high compression ratios compared to other compressing algorithms. Outcomes display that this algorithm works well for various kinds of patient recordings and is even able to provide lossless compression for event-related potentials. According the outcomes, the higher CR. The highest CR is obtained is 75.5, and the lowest PRD is obtained is 0.18 according to the patient records that have the highest CR.**

Keywords*— Data Compression (DC), Arithmetic coding (AC), Wavelet Transform (WT) , Compression Ratio (CR), Biorthogonal Wavelet (BW), ECG lossless compression (ECG lc), Lossless Ccompression (LC)

I. Introduction

ECG is the bio-signal that deals with an electrical activity recording of the human heart. The ECG is utilized in the heart disorders approximation and it is utilized to detect the damage. The ECG signal can be saved efficiently and transmit the huge amount by using the compression techniques. Lossy compression and LC are the two kinds of ECG compression, .

There are two various methods to ECG signals analyzing:

A. By human beings called visual inspection(VI).

B. By utilizend a SPA (Signal Processing Algorithms) called automic analysis (AA) .

In the medical app, a large amount of data are transmitted via the compressed form to define the performance by lossless ECG compression techniques an excellent way[1]. The techniques LC permit ideal reconstruction of the original signal, they produce the high CRs. There is some kind of quantization of the input data that leads to CR. The LC has the economic and efficient data storage along with real-time signals transmission. The lossless DC techniques are the most efficient DC technique. The current requirements is effective compression algorithms for the fast signals transmission, so the best solution to do that is signals compression with better accuracy before transmission [2].

The DC methods are commonly utilized in biomedical signals. The value portends the transmitter and the receiver of the existing sample based-on samples that have already been transmitted. If the existing sample by yi and its predicted value by yi', then for each sample just the prediction error, ei= yi'−yi, needs to be transmitted. The ECG signal can be process a realization of a time series yk generated as[3]:

$$Y_k = \sum_{i=1}^{p} a_i Y_{k-1} + e_k \quad (1)$$

Where, ek is the unpredictable part of Yk. In order to define the auto regressively, an order P is selected and then evaluate the parameter set {ai, i = 1….., P}. The WT is a tool utilized to find the application of signal compression. In the analysis operation of WT, the equation of wavelet mentioned is given below[4]:

$$S(t) = \sum_k \sum_j a_{i,j} c_{j,k}(t) \quad (2)$$

Where k∈ Z are integer indexes, aj,k are the expansion's wavelet coefficients, and cj,k is a wavelet functions set in t[5].

In some clinical practices, the biomedical signals transmission via communication channels are utilized. This communication method need dealing with a huge amount of information, and the example is the ECG signal. WT can be utilized to gain the information from various types of data, including images, audio signals, and others. A group of function is achieved by the quantizer is called as quantization. Quantization is sitting in all DSP (digital signal processing), and it is the operation of implementing a signal in a digital form and rounding-off the values. The round-off error in the quantization is described as a quantization error. Compression is utilized to minimize more files and it is also easy to handle[6].

Compression is performed by data encoding that can be gained by decoding in the original form. The methods of LC are classified by the type of data and then they get compress. The common techniques of lossless coding used are, RLE (Run-length encoding), HE(Huffman encoding), AE(Arithmetic encoding), EC (Entropy coding)[7].

The AC is a commonly utilized in EC scheme, it produces the sequence of intervals by the symbols sequences' probability. The small interval at the end of the latest symbol and the code is produced by choosing a real-number from the interval and transformed them to binary, and then distribute the code values uniformly [8].

This article is organized as follows: In Section 2, a short review of ECG compression related works. The method and materials are briefly explained in Section 3. The results and discussion are presented and commented in Section 6. A conclusion and future works are introduced in Section 8.

II. Related Work

Many related works are introduced in the field of EEG compression, and below mention of some of the related work:

Raiatibanadkooke, et al.[9] introduced a technique of compression by concentrating on compressing of ECG signal with no loss of primary data and furthermore encrypt the signal to preserve it secret from everybody, except for specialists. At this stage, the ECG signal is compressed after determining the heart rate, peak detection, Gaussian noise as well as removing the baseline noise removal. Here, Hoffman encoding is used for compression and encoding for ECG signal. There was no need for any computers to support this goal because mobile processors were used. After the classification of ECG signal, It was found that there is a need to study and analyze the effect of CR and PRD on acquired properties as well as accuracy and sensitivity, in order to check the compression algorithm, utilized.

The suggested work concentrate the on ECG compression, extracting features from the decompressed signal, and PCA (principal component analysis), to further compress and validate data using a classifier. Xiaoxiao Wang et al. [10] presented a novel ECG compression scheme on the basis of the combination of the EMD (empirical mode decomposition) and the DWT (discrete wavelet transform).

The proposed technique stages are described as a following :

Re-mixing EMD and IMF: In this approach, the ECG signal was first separated by the EMD per 1200 sample of the frame . The first two funds from the IMF were added as the first mixed function and the other components were added together as a second mixed function .

DWT and feature point extraction points: The maximum mixed function of the first reconstruction is documented, and the original function can be rebuilt within the cubic spline fitting .

In order to enhance the reconstruction accuracy, computed the error between the original and the reconstructed mixed function of each frame.

Jiali Ma et al. [11] suggested a new ECG compression method for applications of the electronic health by Adapting Fourier Decomposition (AFD) algorithm hybridized with symbol substitution (SS) scheme . The compression consists of tow phases: firstly AFD achieved efficient lossy compression with high fidelity. Secondly, SSs executed lossless compression for the improvement and built-in data encryption which was crucial for electronic health . The 48 ECG records from MIT-BIH arrhythmia benchmark database is validated. Mathematical Foundation of AFD Algorithm. Yang He et al [12] presented The issue of flexibility and the quality of reconstruction that occurred in addressing traditional ECG-based CS. An adaptive ECG compression technique has been introduced, based on the closed-loop control theory, in which CR can be set according to the real-time reconstruction error and support the previous knowledge. A. Bendifallah et al [13] presented technique of a DCT (discrete cosine transform) based progress for ECG compression . The utilizing of a block-based DCT connected to a normal scalar dead zone quantizer and arithmetic coding performed worthy outcomes , ensuring that the suggested technique shows the competitive performances as compared with the most widespread compressors used for ECG compression. Ranjeet Kumar et al. [14], presented a novel study of progress and development in data compression research with a focused study on ECG compression based on 2D-Transform. The authors show that the technique of 2D compression is a novel for present and future perspective for ECG signal records and other periodic or quasi-periodic biomedical signals or electromechanical signals. It does also the better solution for m-Health applications.

III. Method and Materials

A. ECG Overview

One of the most vital and intuitive tests of the patient's current condition is the electrocardiogram (ECG), which describes the electrical function of the heart in the human body. Human heart activity produces electrical waves measured as an ECG signal where the ECG is a biomarker that is produced on the surface of the human body due to the heartbeat. This signal is very important for specialists because it provides the patient's heart condition for the time being. Since most hospitals operate on the patient's electronic patient record (EPR), DC has become a major problem in biomedical electronics as more and more patient maintenance records are required without overcrowding storage available. In addition, the patient's cardiac data is recorded accurately in digital form, so that slight changes in the ECG recording can be traced as a major concern in the field of biomedical signal processing[15][16].

B. ECG processing

During the compression process, the ECG signal passes through several stages, the most important of which is the purification of these signals from the artifacts (noise removal). Artifacts cause a lack of clarity or reading of the heart signal for the specialist. The process of processing an ECG signal starts by capturing the signal, which is often aggregation by the Holter machine. This device is directly connected directly to the patient's body through 12 electrodes.

The function of these electrodes acts as cameras that monitor the patient's pulse closely to give a complete vision of patient health. The process of ECG signal start with the applied WT on the input signal, after which the quantization of these signals. The benefits of quantization are removing a less influential values and memory space saving. Finally applied an AE. The benefits of AE to minimize the coding redundancies sitting in the signal.

In order to read the compressed signal accurately, the ECG signal must be decompressed. The above operations are performed reversely. The inverse is applied in order to extracting the reconstructed signal for reading these signals and extracting clinical important medical information by specialists for accurate diagnosis. The figure (1.1) is the all operation of the proposed algorithm.

STEP 1: input ECG signal from Database.
STEP 2: ECG Signal Artifact Removal.
STEP 3: Applied WT.
STEP 4: Quantized ECG signal.
STEP 5: Applied AC.
STEP 6: Applied IWT.
STEP 7: Finally, the ECG signal reconstructed the same as that of the Original signal.

C. Quantization

The process of converting the values-range to a single-value by compressing them is called quantization. It allocates a large set of input values to the smaller value set. There are two methods to increase the efficiency of quantification in wavelet encoding, by presenting the quantization interval around zero, and by adapted quantization interval size [17].

IV. WAVELET TRANSFORM (WT)

WT is a mathematical instrument that utilized in applications of signal compression. It is a signal representation that utilizes to reconstruct the signal. WT is decomposing the signal to a group of functions called as wavelet. It is limited in small duration. Orthogonal, Bi-orthogonal, Atrous are the kinds of WT [18].
Lossless coding Techniques are :

- HC refer to a “Huffman coding”
- AC refer to “Arithmetic coding”
- BC refer to “Bit-plane coding”
- RLC refer to “Run-length coding”

Here, the AC for compression was used and used WT for decompose the signals. It calculates the inner products of a signal with a wavelet family. The properties wavelet transform has a limited length and have an irregular shape. The discrete wavelet tool and the continuous tools are both tools of WT. The time-frequency and self-similarity analysis exist in the continuous wavelet. The function of DWT is DC, and provide noise reduction[19].

V. ARITHMETIC CODING (AC)

In this AC, it creates non-block codes symbols between the source code and the code where there is a code word in each source code. A set of source codes is assigned to a single math code. The real-time interval code is between 0 and 1.

When the symbols numbers increasing in the message, this means two changes,
1. The interval of the message becomes smaller and based on probability each code.
2. The bits number represented in the interval becomes larger[20][21].

VI. EXPERIMENTAL RESULTS

The experimental data from MIT-BIH arrhythmia dataset is utilized to CR's performance analyzing and testing. Figure 2, display the original and the reconstructed of ECG waveform.

VII. RESULTS AND DISCUSSIONS

The proposed method utilized an approach on WT and AC. The performance of various terms of CRs and PRDs was compared. WT signals are analyzed in both spatial and temporal domains.

To support the described ECG compression technique and to compare with other methods, a sample consists of 21 records started from Rec.100 and ending with Rec 120 from MIT-BIH dataset have been utilized. The records contain a sampling frequency of 360 samples/sec additionally a digital ECG signals.

TABLE (1), COMPRESSION RESULTS OF THE PROPOSED ALGORITHM. THE CR, PRD, PRDN, QS, RMS, ARE CONSIDERED FOR EACH RECORD. TABLE (1) SHOWS THE RESULTS.

Record	CR	PRD	PRDN	QS	RMS	SNR
100	39.9	0.23	7.34	167	2.16	53.8
101	48.7	0.18	4.48	267	1.73	59.4
102	27.9	0.5	15.5	55.5	5.32	69.5
103	33.9	0.33	5.59	100	3.19	58.9
104	20.2	0.34	7.02	217	3.71	55.2
105	59	0.34	5.62	169	3.4	55.8
106	65.2	0.36	5.73	180	3.34	58
107	39.6	0.66	4.71	59.6	7.63	59.5
108	75.2	0.3	10	249	3.47	61.2
109	38.6	0.38	5.06	99.7	4.17	60.8
110	46.1	0.24	6.1	188	2.54	61.4
111	53.9	0.22	5.12	244	1.9	60.7
112	48.3	0.32	4.06	149	3.18	62.6
113	42.9	0.21	9.51	201	2.04	64.3
114	46.8	0.28	4.3	164	2.59	61.8
115	38.7	0.5	3.75	76.9	4.15	62.7
116	47	0.31	6.4	148	2.78	61.4
117	**42.6**	**0.67**	**7.1**	**63.6**	**5.71**	**51.2**
118	**38.5**	**0.47**	**3.42**	**81.8**	**3.95**	**63.4**
119	**45**	**0.29**	**2.73**	**248**	**1.54**	**72**
120	**75.3**	**0.18**	**3.7**	**68.9**	**2.52**	**65.3**

TABLE (1): PERFORMANCE PARAMETERS OF PROPOSED METHOD WITH RECORDS 117-120, AT DIFFERENT COMPRESSION SCORE.

Method	MIT-BIH ECG Record*	CR	PRD	PSNR	RMSE	Time Duration (sec)
Arithmetic Coding	*Rec117*	*42.6*	*0.67*	*12.989*	*2.04E+06*	*1.44*
Arithmetic Coding based Wavelet Transform	*Rec 118*	*38.5*	*0.47*	*17.46*	*8.94E+05*	*1.42*
Wavelet Techniques	*Rec 119*	*45*	*0.29*	*22.794*	*7.99E-16*	*1.42*
Proposed method	*Rec 120*	*75.3*	*0.18*	*25.336*	*9.31E+12*	*1.43*

* Massachusetts Institute of Technology (MIT) and the Boston Hospital (BIH) in 1987 (http://www.physionet.org/physiobank/database/mitdb/)

In Table 2, a different quantization levels on different records with threshold estimation

TABLE (2): SHOW THE QUANTIZATION LEVELS OF DIFFERENT SAMPLES OF INPUT RECORDS

ECG Dataset	Threshold Level (%)	Quantization Level (1)	Quantization Level (2)	Quantization Level (3)
Rec117	2	10	9	8
Rec 118	5	9	8	7
Rec 119	8	7	6	5
Rec 120	9	6	8	9

VIII. PERFORMANCE MEASUREMENTS

In order to measure the performance of compression technique, different parameters are applying over entire ECG signal, and describe below:

A. Compression Ratio (CR): The ratio of original length to the compression length and it can be given as follows:

$$CR = \frac{L_{org}}{L_{comp}} \quad (3)$$

B. Percent of Root-Mean-Square Difference (PRD): PRD is the ratio of the signal power to the original signal power. The PRD is used in measuring distortion. It also gives an average distortion in the reconstructed signal.

$$PRD = \frac{\sqrt{\sum_{i=1}^{N}|x(i)-x'(i)|^2}}{\sqrt{\sum_{i=1}^{N} x(i)^2}} \quad (4)$$

C. Root Mean Square Error (RMSE): the function RMSE can be described as Root Mean Square Error in the following eq. (1.6), this equation used for signal assessment:

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}[x(n)-x'(n)]2} \quad (5)$$

Where *x (n)* is original signal, and *x (n)* is ECG signal improvement.

D. Signal to Noise Ratio (SNR): The SNR can be described as a following:

$$\text{SER} = 10 * \log \quad (6)$$

E. Quality Score (QS): The overall performance of the compression scheme based on the presentation of the distortion percentage quality score (QS) and compression is evaluated according to the following Equation 7:

$$QS = \frac{CR}{\text{PRD (Percentage Root Mean Square Difference}} \quad (7)$$

F. Peak signal-to-noise ratio (PSNR): is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation and expressed by:

$$PSNR = 20.log_{10}(MAX_I) - 10.log_{10}(MSE) \quad (8)$$

Where MAXI is the maximum possible pixel value of the signal.

G. Normalized Percentage Root Mean Square Difference (PRDN:

$$PRDN = \sqrt{\frac{\sum_0^{N-1}(X_{(n)}-Y_{(n)})^2}{\sum_0^{N-1}(X_{(n)}-mean(X_{(n)}))^2}} x100\% \quad (9)$$

ECG compression methods are utilized for ECG signal compression is presented in this article. The two proposed compression techniques are AC and WT. The algorithm is evaluated to measure the performance by using is various parameters. The original ECG signal is showing in Fig 2. AC and WT are used to compressed this signal. In the fig 3, the reconstructed ECG signal is shown. TABLE I, shows the analysis of CR and PRD for different techniques. Various WTs are selected to compare the performance.

IX. CONCLUSION AND FUTURE WORKS

In this paper, an efficient compression algorithm has been proposed which uses transform based on BW followed by the AC technique is presented. The ECG signal is compressed by utilizing the LC such as WT with BW and the AC technique. The performance parameters like CR and

PRD are utilized to assess the performance of the suggested algorithm. Various techniques are utilized for performance analyzing which is matched by parameters assessment. The suggested algorithm shows the best outcomes in term of CR is 75.3 and PRD is 0.18. This method is readily programmable and it has a depressed computational load. ECG signals will be easier to store and use in the real-time application. In the future, the result of compression can be improved using different methods without increasing the computational burden..

REFERENCES

[1] Chandan Kumar Jha aheshkumar H. Kolekar "Performance Analysis of ECG DC using Wavelet Based Hybrid Transform Method," International Confrence on icrowave, Optical and Communication Engineering, 2015.

[2] Anjeet Kumar Anil Kumar "Dual Tree DWT Analysis based Electrocardiogram Signal Compression using Zero Coding Technique " ICECS 2015, pp. 624-629, 2015.

[3] M. Ni., and M. Ziv. , Wavelet-based unsupervised learning method for electrocardiogram suppression in surface electromyograms, Med. Eng. Phys. 38 (3), 248–256, (2016).

[4] Isasi, I., Irusta, U., Aramendi, E., Age, J., & Wik, L. (2017). Characterization of the ECG compression artefact caused by the AutoPulse device. Resuscitation, 118, e38.

[5] Elgendi, M., Mohamed, A., & Ward, R. (2017). Efficient ECG Compression and QRS Detection for E-Health Applications. Scientific reports, 7(1), 459.

[6] Ziran, P. E. N. G., Guojun, W. A. N. G., Jiang, H., & Shuangwu, M. E. N. G. (2017). Research and improvement of ECG compression algorithm based on EZW. Computer methods and programs in biomedicine, 145, 157-166.

[7] Soares, S. C., & Pinho, A. J. (2017, June). Impact of the Acquisition Time on ECG Compression-Based Biometric Identification Systems. In Pattern Recognition and Image Analysis: 8th Iberian Conference, IbPRIA 2017, Faro, Portugal, June 20-23, 2017, Proceedings (Vol. 10255, p. 169). Springer.

[8] Tun, H. M., Moe, W. K., & Naing, Z. M. (2017). Analysis on ECG DC Using Wavelet Transform Technique. International Journal of Psychological and Brain Sciences, 2(6), 127.

[9] Raeiatibanadkooki, Mahsa, et al. "Compression and encryption of ECG signal using wavelet and chaotically Huffman code in telemedicine application." Journal of medical systems 40.3,1-8, 2016.

[10] Xiaoxiao Wang et al., "ECG Compression based on combining of EMD and Wavelet Transform", IEEE, Electronics Letters, Vol. 52, Issue 9, p.p. 1588-1590, 2016.

[11] Jiali Ma, TanTan Zhang and MingChui Dong, "A Novel ECG data compression method using Adaptive Fourier decomposition with security guarantee in e-Health Applications", IEEE, Journal of biomedical and health informatics, Vol 9, Issue 3, pp 986-994, 2015.

[12] Yang He et al. , "ECG Compression Scheme with prior knowledge support based on compressive sensing", IEEE, p.p. 1-5, 2015.

[13] A. Bendifallah, R. Benzid and M. Boulemden, "Improved ECG Compression Method using DCT", IEEE, Electronics Letter, Vol 47, Issue 2, Pp 87-89, 2011

[14] Ranjeet Kumar, A. Kumar, and G. K. Singh, " Electrocardiogram Signal Compression Based on 2D-Transforms: A Research Overview", Journal of Medical Imaging and Health Informatics, American Scientific Publishers, Vol. 6, 285–296, 2016.

[15] Carvalho, J. M., Brãs, S., Ferreira, J., Soares, S. C., & Pinho, A. J. (2017, June). Impact of the Acquisition Time on ECG Compression-Based Biometric Identification Systems. In Iberian Conference on Pattern Recognition and Image Analysis (pp. 169-176). Springer, Cham.

[16] Ieong, C. I., Li, M., Law, M. K., Mak, P. I., Vai, M. I., & Martins, R. P. (2017). A 0.45 V 147-375 nW ECG Compression Processor With Wavelet Shrinkage and Adaptive Temporal Decimation Architectures. IEEE Trans. VLSI Syst., 25(4), 1307-1319.

[17] Jati, G., Rachmasari, A. R., Jatmiko, W., Mursanto, P., & Sediono, W. (2017, September). An efficient secure ECG compression based on 2D-SPIHT and SIT algorithm. In Big Data and Information Security (IWBIS), 2017 International Workshop on (pp. 155-160). IEEE.

[18] Elgendi, M., Mohamed, A., & Ward, R. (2017). Publisher Correction: Efficient ECG Compression and QRS Detection for E-Health Applications. Scientific reports, 7(1), 17033.

[19] Roy, R. B., Roy, A., Mukherjee, A., Ghosh, A., Bhattacharyya, S., & Naskar, M. K. (2019). Sparse Encoding Algorithm for Real-Time ECG Compression. In Recent Trends in Signal and Image Processing (pp. 31-38). Springer, Singapore.

[20] Burguera, A. (2018). Fast QRS detection and ECG compression based on signal structural analysis. IEEE Journal of Biomedical and Health Informatics.

[21] D. S. Arsa, G. Jati, A. Santoso, R. Filano, N. Hanifah, and M. Rachmadi, "Comparison of image enhancement methods for chromosome karyotype image enhancement," Jurnal Ilmu Komputer dan Informasi, vol. 10, no. 1, pp. 50–58, 2017.

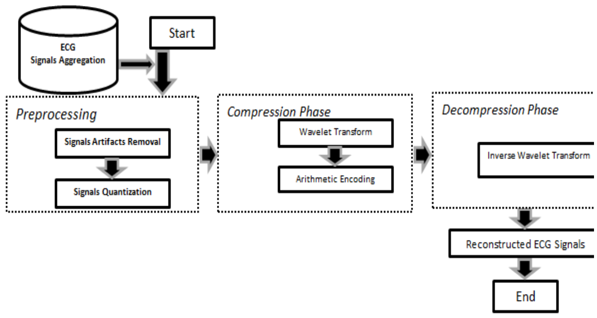


Fig. (1) Simple ECG Signal Compression flowcharting

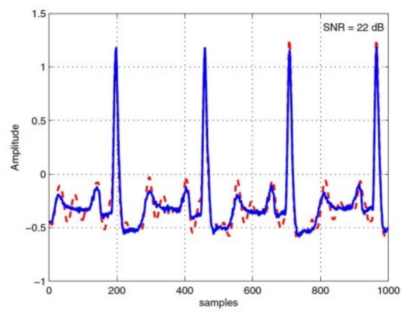


Fig. 2. The Original ECG Signal and the Reconstructed Signal for Rec. 120.

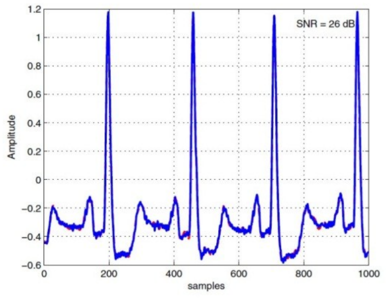
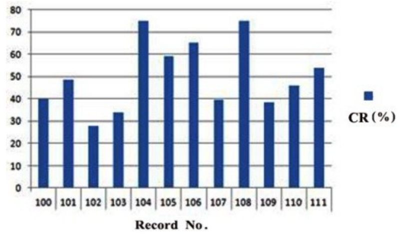
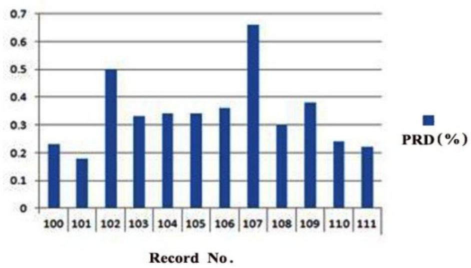


Fig. 2. The Original ECG Signal and the Reconstructed Signal for Rec. 120.



(a)

Fig. 3 (a) CR for 12 records from 100- to 111 randomly



(b)

Fig. 3 (b) PRD for 12 records from 100- to 111 randomly