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LOSSLESS ELECTROCARDIOGRAM COMPRESSION TECHNIQUE AND GSM BASED TELE-CARDIOLOGY APPLICATION

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Abstract- Software based efficient lossless Electrocardiogram compression and transmission scheme is proposed here. The algorithm has been tested to various ECG data taken from PTB Diagnostic ECG Database. The compression scheme is such that it outputs only ASCII characters. These characters are transmitted using Global System for Mobile Communication based Short Message Service system and at the receiving end original ECG signal is brought back using the reverse logic of compression. It is observed that the proposed algorithm offers a

moderate to high compression ratio (7.18) without any alteration of clinical information (PRD = 0.023%) with an excellent Quality Score (312.17).

Index terms: Sign Byte, Amplification, Grouping, ASCII Character, SMS.

I. INTRODUCTION

Electrocardiogram (ECG) describes different electrical phases of a cardiac cycle and represents a summation in time and space of the action potentials generated by cardiac cells. ECG provides a measure of the electrical currents initiated in the extra-cellular fluid because of the potential changes across the cell membrane [1]. A typical normal ECG trace is shown in figure 1. The ECG is described by waves, segments and intervals. Waves are tagged using the letters P, QRS, T. Segments are time spans between waves and intervals are time lengths that include waves and segments. The shape and size of the P-QRS-T wave and the time intervals between various peaks contain useful information about the nature of probable disease afflicting a heart. P, Q, R, S and T letters were chosen in the early days of ECG history and were chosen arbitrarily [2].

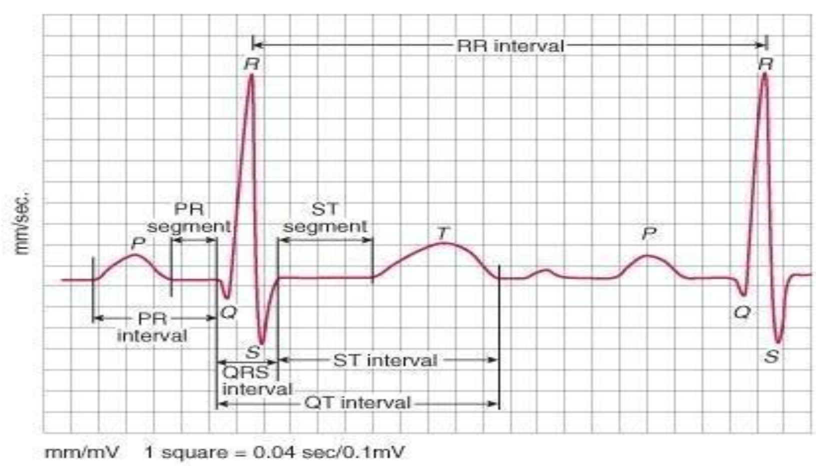

Figure 1. A normal ECG trace

However, by the very nature of bio-signals, reflection of cardiac abnormalities would be random in the timescale. Hence the study of ECG pattern and heart rate variability have to be carried out for extended periods of time (i.e., for 24 h) as done in Holter monitoring system. Naturally the volume of the data handled would be enormous. Therefore we must need a way to reduce the data storage place without making considerable change in the reconstructed signal and this is exactly the goal of many existing ECG signal compression methods proposed in the literature over the last 4 decades. ECG signal compression techniques can be broadly classified into three major categories: (i) direct data compression, (ii) transformation methods and (iii) parameter extraction techniques. Direct data compression techniques ([3-10]) generally retain samples that contain important information about the signal and discard the rest. Transformation based compression techniques generally detect the redundancies utilizing the spectral and energy distribution analysis. Among transformation schemes, wavelet transformation (WT) [11-15] has become very popular due to the fact that the time–frequency kernel for the WT-based method can better localize the signal components in time–frequency space. Except WT, orthogonal transform [16] and Discrete Cosine Transform [17] have also been used for getting compressed ECG data. Direct and transformation based compression methods are reversible i.e. original signal can be brought back using reverse programming approach. On the other hand parameter extraction methods [18] for compression are irreversible process. These methods are mainly based on linear prediction and long-term prediction methods. In addition to the previous categorization, ECG signal compression schemes can also be classified into lossy and lossless methods. It is obvious that a lossy method can achieve better compression performance but it may lose some important clinical information. On the other hand a lossless method offers a moderate to high compression ratio without jeopardizing the morphology. From juridical and clinical point of view [19, 20], lossless compression is very much important.

Compression of ECG data is essential not only for optimal usage of computer memory but also for increasing the spectral efficiency of communication link for bio-telemetry or tele-cardiology applications. In recent days a huge numbers of mobile telemedicine system design techniques were proposed in the literature [21-35]. Global System for Mobile Communication (GSM) link was used in [36] to develop an emergency tele-monitoring device. Use of Wireless Mesh Networks (WMN) [37] and Code Division Multiple Access (CDMA) network [24] were proposed in telemedicine system. Short Message Service system (SMS) was also used in [38-40] to transmit compressed ECG signal for remote health care system. Latest wireless communication technologies, such as GPRS, 3G, EDGE and WiMAX provide superior data transmission rates than 2G GSM network. But these high end wireless communication technologies have become popular in economically developed metropolitan cities. Majority (80.8%) of the cellular phone users around the globe is still 2G GSM users [41].

One of the growing issues in rural health care system in India is to broaden the service among the poor population distributed at huge geographical area with poor connectivity in terms of infrastructure. ECG is considered as one of the principal physiological signal to detect the cardiac abnormalities of human being. Principal motivation behind this work is to develop a low cost, reliable and user friendly remote tele-cardiology system for compression and transmission of ECG signal which will give support to the rural health care system.

The proposed compression algorithm is divided into four major steps: viz., inter-sample difference computation, sign byte generation, amplification and grouping. The whole compression module is such that the compressed file contains only 8-bit ASCII characters. For getting fast response from expert cardiologists, the compressed file is transferred to cardiologist’s mobile phone in form of SMS. The thing is to be done at the doctor’s or cardiologist’s end is to transfer all those SMS to the computer or laptop. There is also a reverse algorithm which concatenates all those SMS and produces the reconstructed ECG signal after proper decompression.

II. METHODOLOGY

The proposed scheme is divided into following three main sections: (a) Data compression (b) Transmission and Reception and (c) Data reconstruction. All these compression, transmission-reception and reconstruction algorithms are explained sequentially in rest of the sections. Block schematic of the proposed algorithm is shown in figure 2.

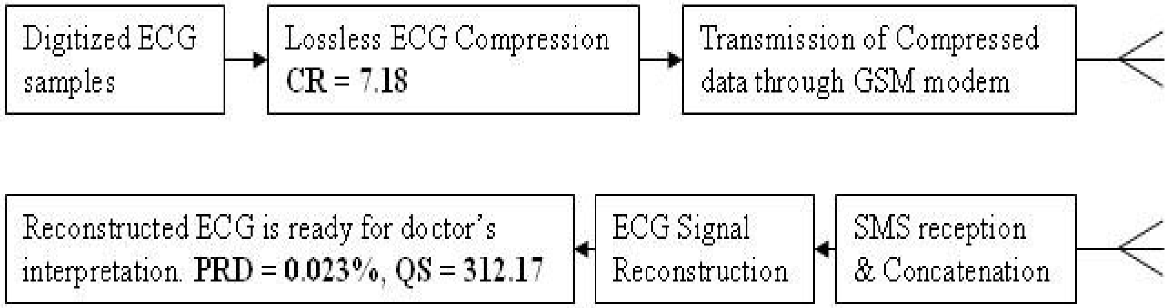

Figure 2. Block schematic of the proposed algorithm.

a. Data compression protocol

The algorithm proposed by us in [42] is implemented here to compress the ECG data in lossless manner. From the input ECG data file only the 'Voltage' values are taken. As the sampling frequency of the original ECG data is known (1 KHz for PTB Diagnostic ECG Database), the 'Time' axis can be easily generated during data reconstruction. Therefore, concentration is given only to compress the 'Voltage' values. At a time eight consecutive digitized ECG samples are taken from the input file and saved in an array. A sample array is shown below.

0.021	0.021	0.025	0.023	0.024	0.031	0.035	0.038

For getting smaller numbers and consequently better compression a difference array is constructed which contains the difference of every ECG sample and it's preceding. A sample array containing the difference is shown below.

0.021	0	0.004	-0.002	0.001	-0.007	0.004	0.003

The sign of the every element of this array is checked. For every positive number a binary zero (0) and for every negative number a binary (1) is taken as sign bit for that corresponding difference value. Decimal equivalent of this binary string will be used as the sign byte for those corresponding eight 'Voltage' values. Obeying this rule, for this particular case, a string likes '00010100' whose decimal equivalent is 20 is found. The sign byte is printed in the output file in its corresponding ASCII character. But the problem occurs if the corresponding ASCII of any decimal equivalent sign byte becomes some special characters like 10 (line feed), 13 (carriage return), 26 (substitution) or 255 (blank). Those numbers can be printed in character form but at the time of data reconstruction these values (13, 26 and 255) will be considered as 'End of File (EOF)' by the compiler and the program will get terminated. Therefore those numbers are replaced with some other suitable numbers provided an extra bit say ('rs') is sent along with this sign byte. After getting the sign byte, all negative numbers in the difference are made positive by multiplying -1. Now each and every number in the difference array is multiplied by 1000 because in standard ECG database and also in PTB-DB, voltages are recorded up-to three decimal points. A sample array after amplification is shown below.

21	0	4	2	1	7	4	3
a[0]	a[1]	a[2]	a[3]	a[4]	a[5]	a[6]	a[7]

Those amplified integers are normalized maintaining some logical criteria and the normalization constant is placed in a variable (say 'ii'). Finally 'rs' and 'ii' is printed in character form. Three variables have been taken (say q, r and s) to denote the indexes of critical numbers (255, 10, 13, and 26) among those amplified integers. After marking those positions, critical numbers are replaced in proper way. Amplified integers are grouped maintaining some essential logical criteria. Three types of grouping are considered here namely (1) forward grouping, (2) reverse grouping, (3) no grouping. Forward grouping will be considered if any 'a[i]*100 + a[i+1]' is less than 255. Reverse grouping will be considered if any 'a[i+1]*100 + a[i]' is less than 255. If both the forward and reverse groupings are not possible, numbers are kept as it is and this is called no grouping. After grouping the above a[] array becomes as below.

21	204	107	4	3
Reverse grouping	Reverse grouping	Forward grouping	No grouping	No grouping

Extra three variables have been taken (say k, z and u) to denote the positions of these forward, reverse and no grouping respectively. At last each set of grouped or not-grouped integers along with other necessary information (sign bit, k, z, u, etc.) will be printed in the output file in ASCII character form maintaining the following format.

Sign-Bit	Grouped/Ungrouped Integers	k	z	u	r	s	q	rs+ii

The algorithm will be executed again and again until all the digitized ECG samples present in the input file have become compressed. The compressed file can be preserved for later diagnosis purpose or it can also be sent to some diagnostic centre or to some expert cardiologist's for fast response.

b. Transmission and reception protocol

The compressed data file contains only 8-bit ASCII characters and hence GSM based SMS is chosen to establish the communication between remote patient and the cardiologist. An 'i-300' GSM modem linked with the computer serial port was used to send SMS. The application software designed for this purpose chooses the compressed file and transmits the same using the GSM modem obeying its protocol.

GSM SMS system can transmit only 7-bit ASCII characters (0-127) but the compressed file contains all 8-bit ASCII characters (0-255). Therefore every character in the compressed file is broken into two suitable 7-bit ASCII characters. Although GSM SMS support 7-bit ASCII characters but not all. There are some specific 7-bit characters which cannot be transmitted through SMS. For example, all characters between (0-31), 59, 61, (91- 94), 96 and (123-127) cannot be transmitted through GSM SMS. ASCII characters ranging from 0-31 are reserved for some special operation [43]. ASCII characters of 59 (;), 61 (=), 91 ([), 92 (\), 93 (]), 94 (^), 96 (`), 123 ({), 124 (|), 125 (}), 126 (~) and 127 (⌂) can be transmitted through GSM SMS but in the received SMS file there will be some other characters except these. Hence these characters should be handled in different way. The rule followed here to convert 8-bit to 7-bit ASCII character is very simple and is described below.

Two variables are taken and named 'MSB' and 'LSB' to hold two 7-bit ASCII characters. For any 8-bit ASCII less than or equals to 31, MSB is set to 32 and LSB is set to '32 + that 8-bit ASCII'. Therefore, both MSB and LSB will be always greater than 31 and therefore can be transmitted through GSM SMS. Although 27 and 29 fall in this range but after adding 32 with these two numbers, they become 59 and 61 respectively.

These two characters can't be transmitted through SMS. For these numbers MSB is set to 33 and LSB is set to 'Number+33'. Figure 3 demonstrates the algorithm.

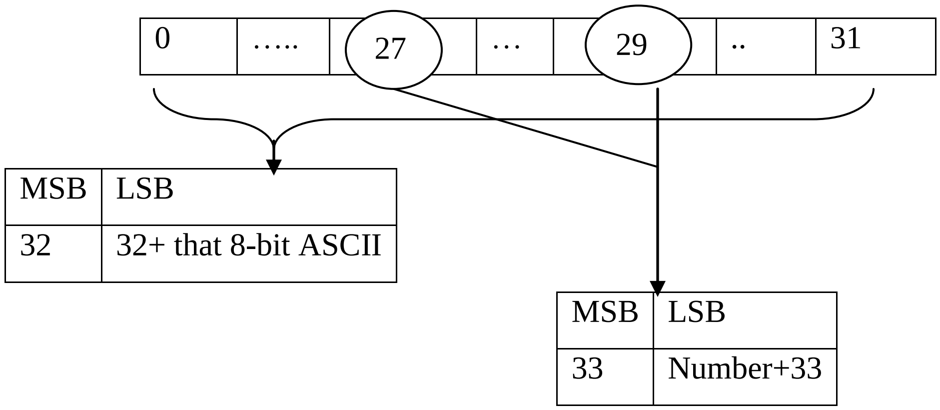

Figure 3. 8 bit to 7 bit character conversion algorithm for the range 0 to 31.

A different technique is used for the numbers ranging from 32 to 127. For these numbers, MSB is set to 34 and LSB is set to the same value as the original. Although 59, 61, (91-94), 96 and (123 – 127) fall in this range but these characters can't be transmitted through SMS. Therefore these are tackled in a different way. For these numbers MSB is set to 35 and LSB is set to 'Number-5'. Figure 4 demonstrates the operation.

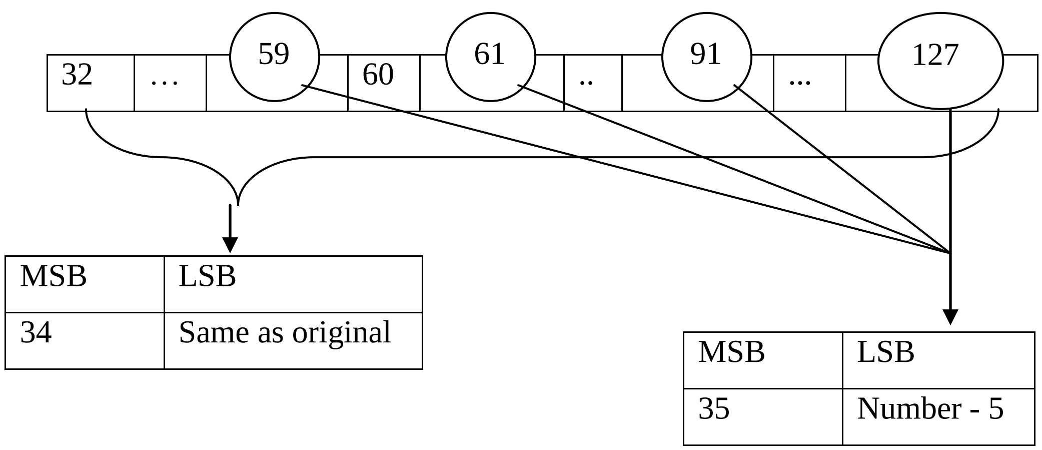

Figure 4. 8 bit to 7 bit character conversion algorithm for the range 32 to 127.

For the numbers ranging from 128 to 218, MSB is set to 36 and LSB is set to ‘number - 100 + 4’. Here also the same problem occurs for the number 155, 157, (187-190), and 192, and handled in the same way explain before. Figure 5 shows the operation.

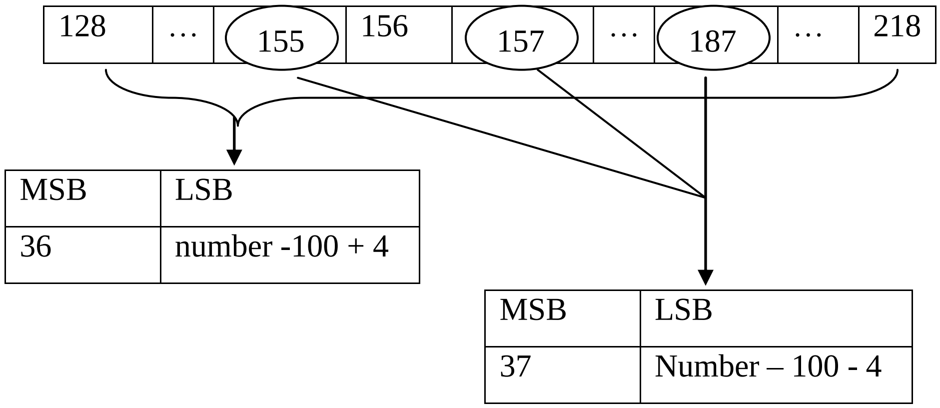

Figure 5. 8 bit to 7 bit character conversion algorithm for the range 128 to 218.

For the last characters set (219-255) MSB is set to 38 and LSB is set to ‘Number -200 + 13’. Also in this range, problem arises for the number 246 and 248 and tackled in the same way. Figure 6 illustrate the operation.

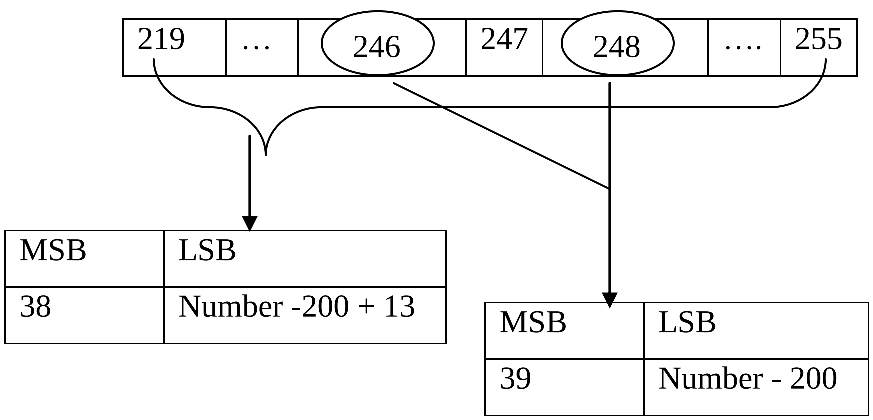

Figure 6. 8 bit to 7 bit character conversion algorithm for the range 219 to 255.

The thing is to be maintained that both MSB and LSB must exist in valid 7-bit ASCII characters for transmission through GSM SMS and the combination of these two must be unique for every 8-bit ASCII character. Both MSB and LSB are printed in the output file.

In text mode, GSM modem can transmit 160 characters per SMS. Therefore an algorithm is developed which divides the compressed data file into a number of small files each containing 160 7-bit ASCII characters. Among those 160 characters, the first character is reserved for patient ID, second and third characters are reserved for message numbers and rest 157 characters are used for transmitting the compressed ECG data. Now those small data files are transmitted to doctor's mobile phone through the 'i-300' GSM modem with the help of AT commands. Excluding those 'not-used' characters, at a time 84 patients' compressed ECG file can be transmitted to a particular mobile phone and each patient ID can have 7056 (84 X 84) SMS. As the patient ID and SMS number is embedded inside the message body, multiple patients' messages can be transmitted simultaneously to a particular mobile phone and if any SMS is transferred before it's previous due to some network problem or something else, there will be no effect at the time of data reconstruction. GSM modem used for this purpose is shown in figure 7.

Figure 7. An 'i-300' GSM modem.

At the doctor's end, all those received SMSs are to be transferred from the mobile phone to the computer or laptop via USB cable, Bluetooth technology or by any means. There is also a reverse algorithm which concatenates all those SMS according to their SMS number of a particular patient ID, converts 7-bit to 8-bit ASCII characters and makes separate file for different patient ID. 7-bit to 8-bit ASCII conversion is done using just the reverse algorithm. A 'Samsung Wave 525' mobile is used at the receiver end to receive SMS. The SMS generation and concatenation algorithm is implemented on MATLAB 7.1 platform.

c. Data reconstruction protocol

After compression, transmission and reception, now it is the time to reconstruct the ECG signal for cardiologist's visual inspection and decision making purpose. Reconstruction algorithm is developed using just the reverse logic of compression. This module takes one set of ASCII character from the compressed ECG data file at a time and equivalent ASCII values are saved in an array and then the decompression algorithm is applied on those ASCII values to reconstruct original eight 'Voltage' values. The first ASCII value among those is the 'Sign-byte' of those eight voltage values. Following ASCII values are grouped or not-grouped integers, grouping positions, position of critical number and 'rs + ii', respectively. Each of these is necessary to bring back the original eight voltage values. Depending on the value stored in 'rs', 'Sign-byte' is modified as per need. The variable 'k', 'z', and 'u' denote the positions of forward, reverse, no grouping, respectively. The original eight voltage values are generated using just the reverse logic of grouping. Now 'r', 's' and 'q' variables are taken into account. These variables indicate the position of the critical numbers (10, 13, 26 and 255) in the ungrouped data. So, original values are brought back. Using the variable 'ii', ungrouped integers are properly modified, as the reverse was done during compression (section 1) while 'Normalizing' the array. In the next step, the Sign-byte will be converted into its corresponding 8-bit binary equivalent. In the binary string if any bit is '1' then the corresponding ungrouped integer will be multiplied by (-1). Now, every number is divided by 1000. These numbers are the difference between two neighbor voltages. To get the original, each number is added with the previous value. A variable 'x' (say) is declared and is initialized with zero (0). For PTD-DB ECG database the sampling frequency of the original ECG signal is 1 kHz. Therefore the sampling interval is 0.001 second. Hence, in each iteration, ‘x’ will be incremented by the sampling interval and will be printed with the reconstructed ECG samples.

III. RESULT

In biomedical data reduction, we usually determine the clinical competence of the reconstructed signal through visual inspection. We may also measure the difference between the original and the reconstructed signal mathematically. Such a numerical measure is the percent root-mean-square difference, PRD, given by

$$PRD\% = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}{\sum_{i=1}^{n} y_i^2}} X100\%$$

Where y_i and $\bar{y}_i$ represents the original and reconstructed ECG sample respectively.

The Compression Ratio (CR), which is defined as below, is also calculated.

$$CR = \frac{ECG\_data\_file\_size(original)}{Compressed\_File\_Size}$$

One another numerical measure Quality Score (QS) was proposed in [44] to quantify the overall performance of compression algorithm. A high score represents a good compression performance.

$$QS = \frac{CR}{PRD}$$

The compression algorithm [42] achieves PRD of about 0.023%, CR of about 7.18 and QS of about 312.17. Figure [8 to 13] show different original, reconstructed and the difference between original and reconstructed ECG signals of different leads of different ECG files processed by this algorithm. Only the reconstructed ECG signal will be produced at the doctors’ end. Differences between original and reconstructed signals are shown here only to give an idea about the performance of the proposed algorithm.

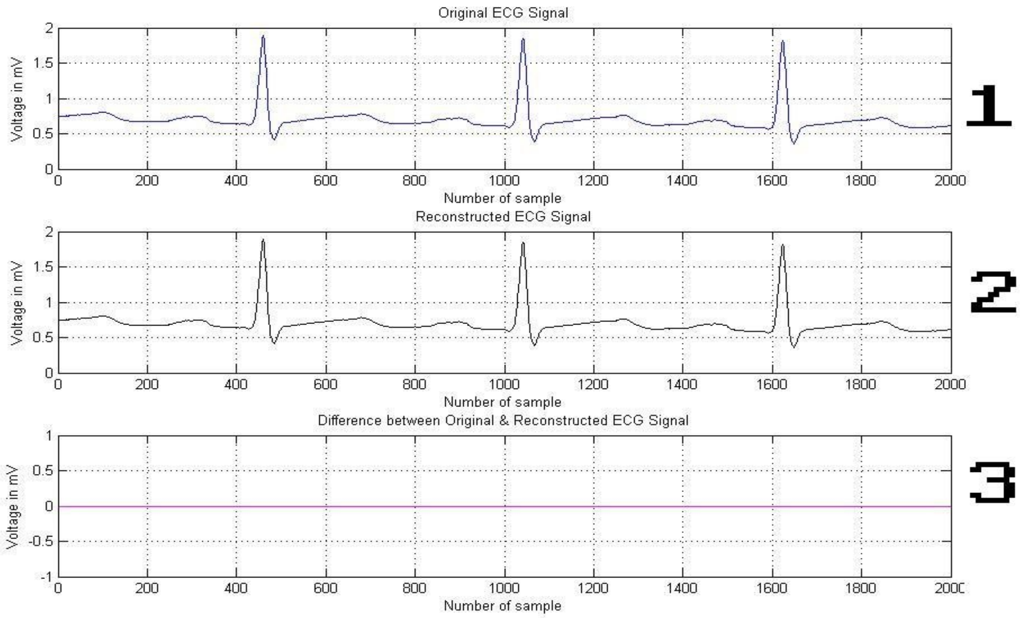

Figure 8. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File:0273, Lead v6 (Normal), first 2000 samples.

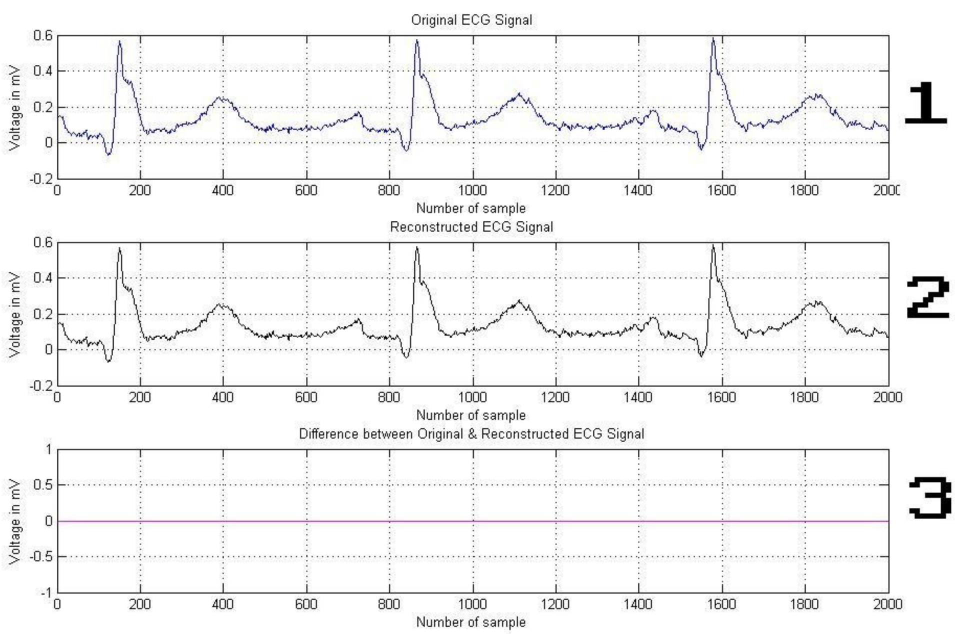

Figure 9. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0553 Lead I, (Myocardial Infarction), first 2000 samples.

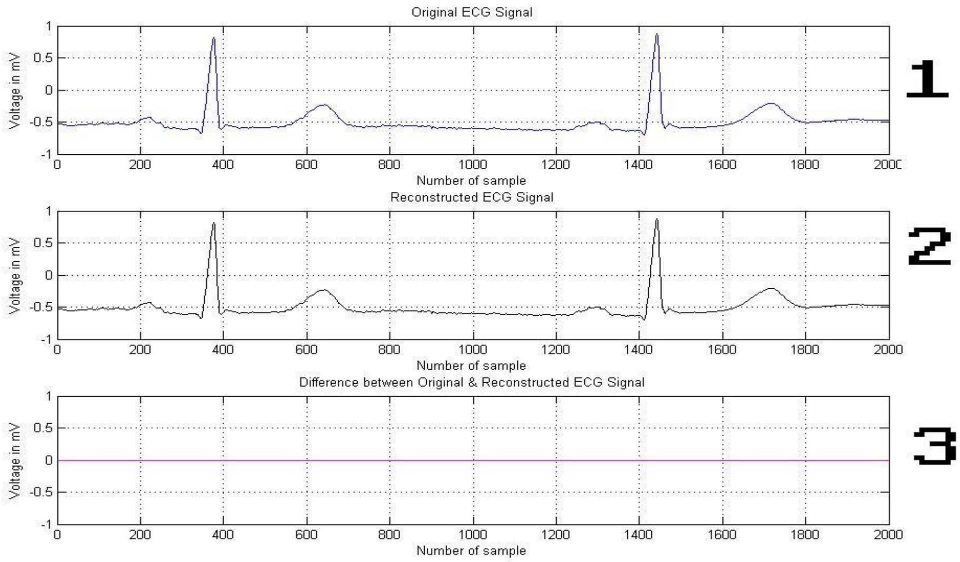

Figure 10. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0305, Lead aVF (Normal), first 2000 samples.

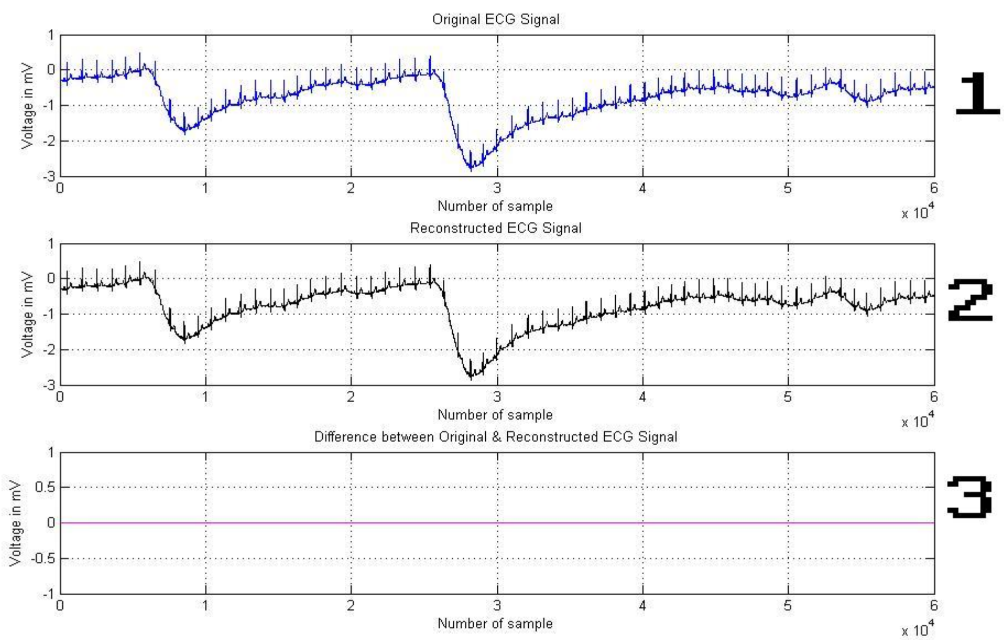

Figure 11. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0464re, Lead III, (Normal) first 60000 samples.

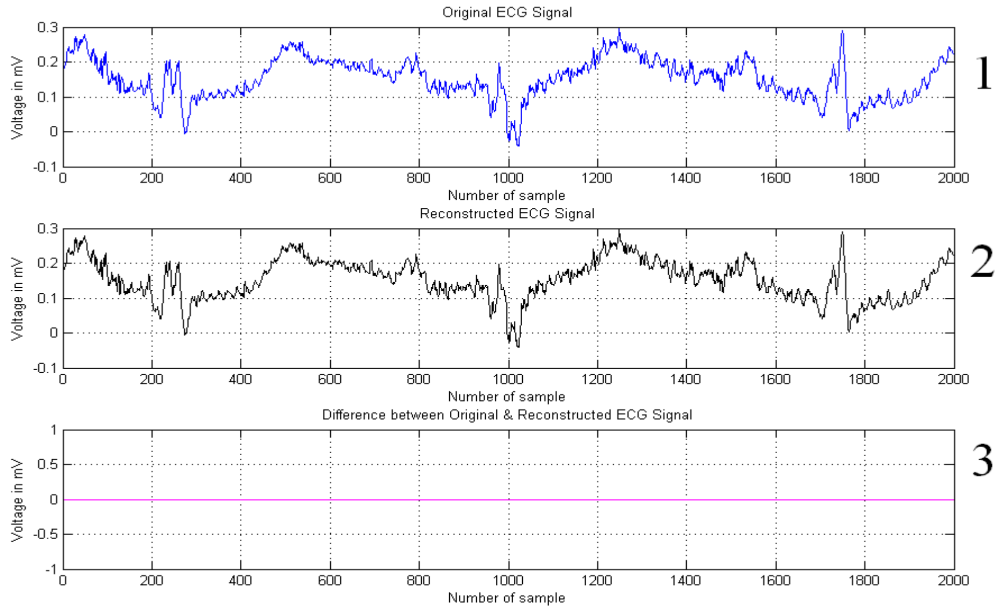

Figure 12. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0021ARE, Lead aVf, (Myocardial Infarction) first 2000 samples.

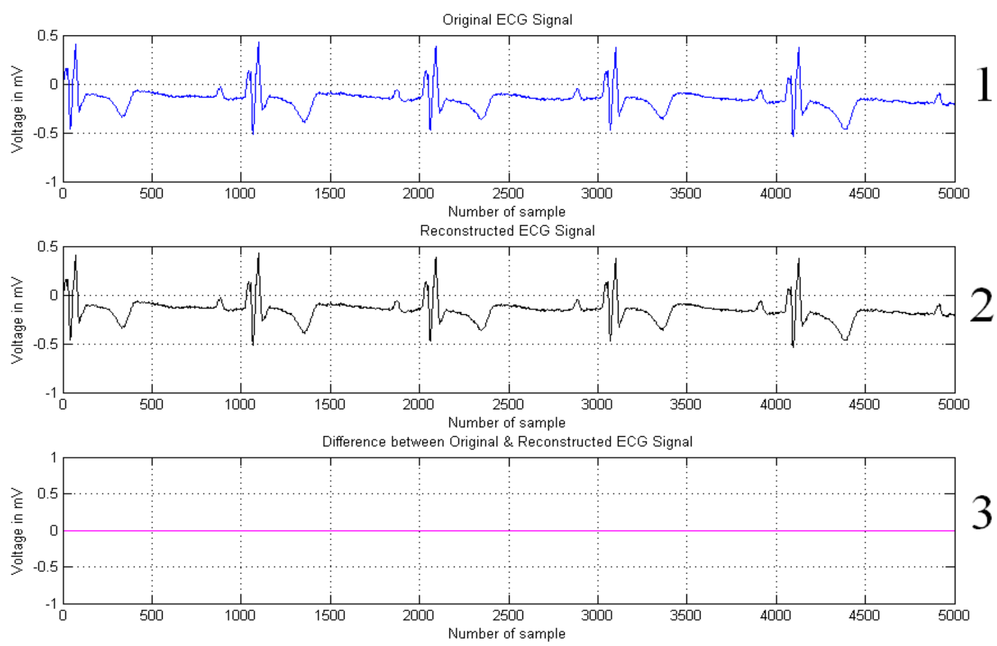

Figure 13. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0431, Lead v3, (Bundle Branch Block) first 5000 samples.

One ECG cycle consist of a P wave followed by a QRS complex and a T wave. It is observed that on average 12 SMS is required to transmit two complete ECG cycles. As the output file contains only ASCII characters, some standard ASCII compression algorithm can further compress the data. Original and reconstructed ECG signals are checked by renowned cardiologists and they have given their valuable comments. According to their visual inspection there is no difference between the original and reconstructed ECG signal. PTB diagnosis ECG database (http://physionet.org/cgi-bin/atm/ATM) was used to assess the performance of the proposed algorithm. This library contains a huge collection of all 12 lead simultaneous ECG recordings and the database contains a high percentage of pathological ECG.

IV. CONCLUSION AND DISCUSSION

The lossless compression technique which is used to compress the ECG signal gives PRD of about 0.023% and QS of about 312.17. Therefore almost no difference can be expected mathematically between original and reconstructed signal. Cardiologists' opinion also supports these numerical outcomes. According to their visual inspection, "original and reconstructed ECG tracings are similar in all aspects". From figure [8 to 13] it is clear the compression module is capable enough to handle clean as well as noisy ECG signals regardless of their morphology. Compressed file can be preserved for later diagnosis purpose or it can also be transmitted to doctors' mobile phone to consult about the patient's heart in urgent situation. If any cardiac abnormality is found, doctor can easily send back his/her concern over phone or also by an SMS. Information about the patient's age, sex, blood pressure, Photoplethysmogram (PPG), medical history etc. which are also important during diagnosis, can also be transmitted through an extra SMS. This will be included in our future research to come. It is always true that at emergency or serious cardiac condition such as heart attack (Myocardial Infarction), one will try to reach hospital instead of sending SMS to a physician. But, primary level of deformity can be detected and cured if the module is used at an earlier stage. Effort has been to given to make the complete module user friendly as far as possible so that any one who has only the preliminary knowledge about computer can use the module at the patient side. Multi patient simultaneous ECG transmission to a particular mobile phone is an added advantage of this proposed scheme over other methods [38, 39]. The transmission and reconstruction protocol has also been tested on the compressed files obtained using [8-10].

Research on ECG feature extraction [45-47] and classification [48] is being carried out and we strongly believe that the combined module of ECG signal compression, transmission, reconstruction, feature extraction and classification could be a better choice in telemedicine application. Moreover the system could be a solution to the inadequate infrastructure in rural health management in India. In certain season, the connectivity in remote villages particularly in hilly regions becomes very poor. Therefore the vast rural population can be benefited from using this system.

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