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].

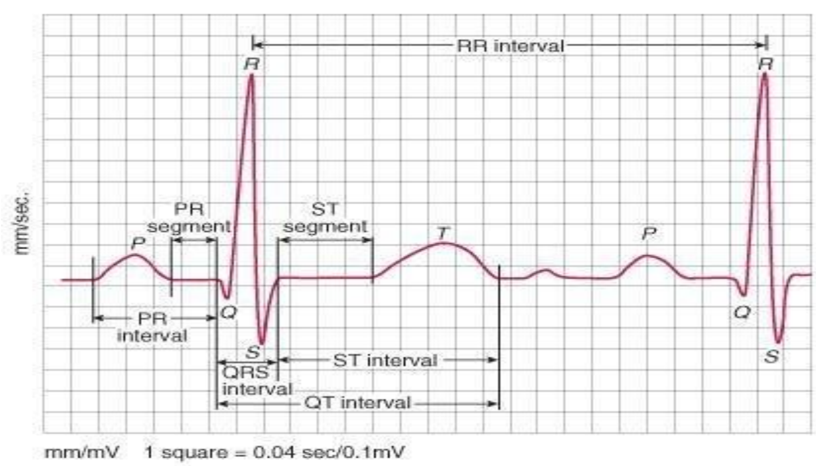

Figure 1. A normal ECG trace

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

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.

(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.

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.

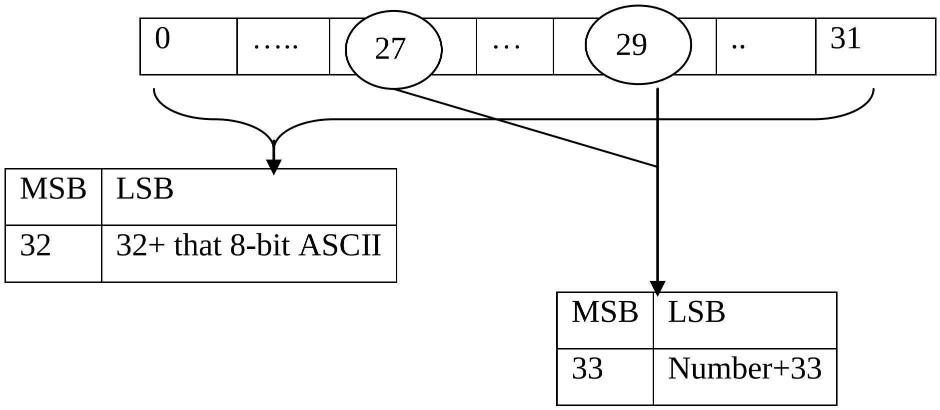

Figure 3. 8 bit to 7 bit character conversion algorithm for the range 0 to 31.

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.

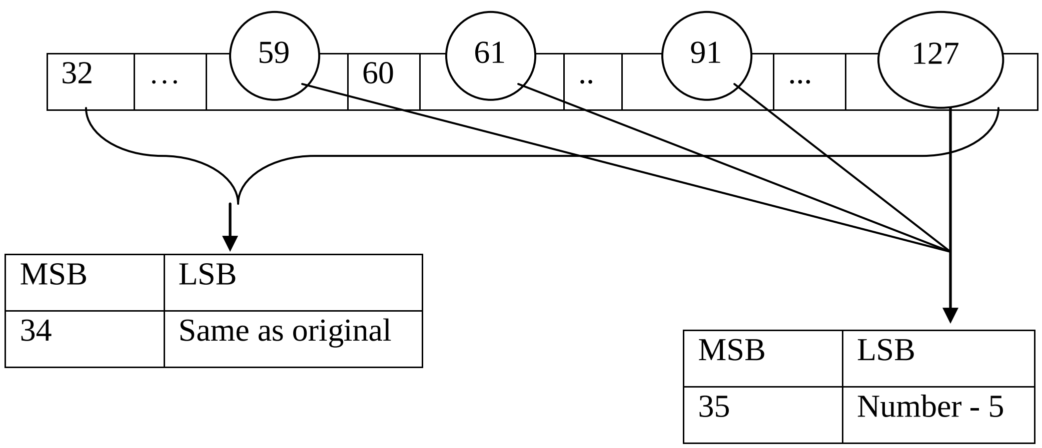

Figure 4. 8 bit to 7 bit character conversion algorithm for the range 32 to 127.

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.

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

$$PRD\% = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}{\sum_{i=1}^{n} y_i^2}} X 100\%$$

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.

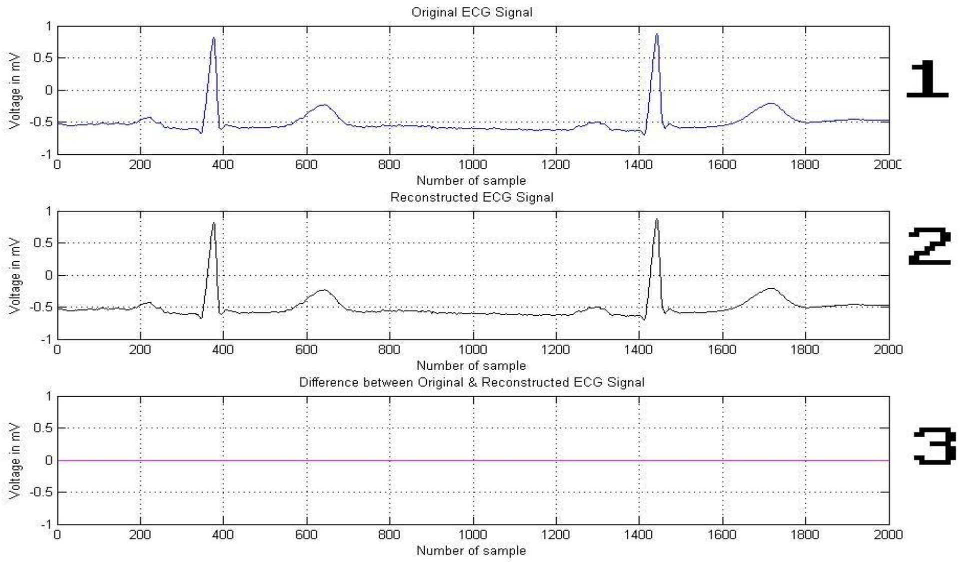

Figure 10. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0305, Lead aVF (Normal), first 2000 samples.

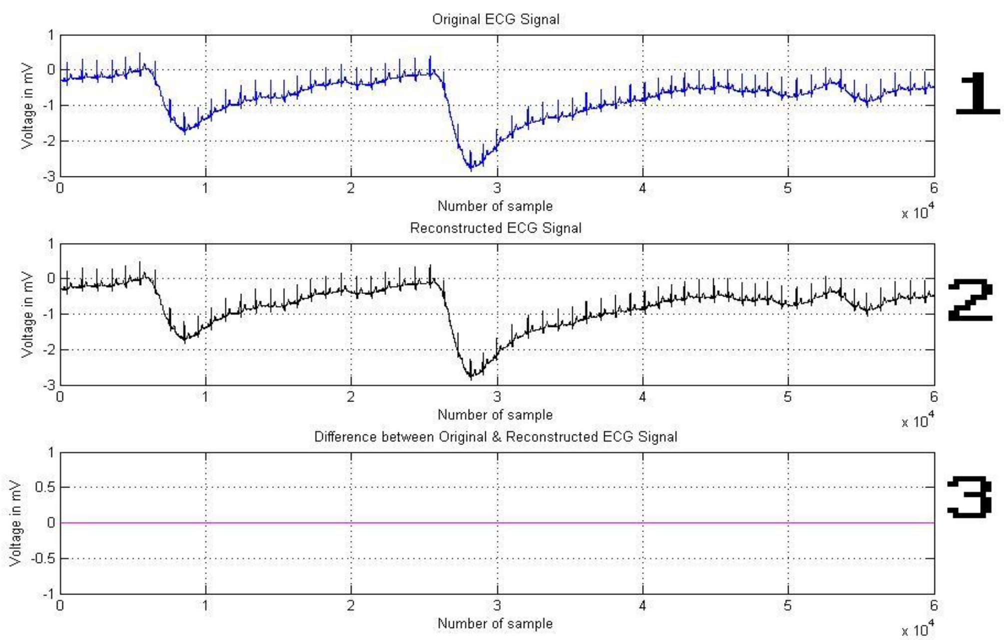

Figure 11. Original (Blue-1), Reconstructed (Black-2) and Difference between original and reconstructed ECG signal (Magenta-3), File: S0464re, Lead III, (Normal) first 60000 samples.

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

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