EVALUATION OF ECG SIGNAL USING COMPRESSIVE SENSING

R.MeenaKshi, Dr.C.Hemanth, Dr.R.Menaka,
Research Scholar, Assistant Professor (SG),
Associate Professor,
School of Electronics Engineering,
VIT University,
Chennai.
r.meenaKshi2015@vit.ac.in
ph: 7798847035;
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Abstract

Wireless body sensor networks are increasingly being used for continuous remote health monitoring of patients suffering from cardiac diseases by collecting real time data and transmitting them to health centers. The sensor nodes along with the device collect, store and transmit a lot of data which results in device constraints due to energy consumption. This paper first compares two traditional system design architecture and one proposed design utilizing compressive sensing that could be employed with devices for ECG signals and makes a qualitative comparison of energy consumption associated with each architecture with the conclusion that architectures utilizing compressive sensing can be relatively energy efficient. Next, the technique of compressive sensing is evaluated on data from MIT-BIH arrhythmia database to determine achievable data compression with acceptable recovery. An approximate 30% and
40% compression ratios are achievable with no loss of data using the Fourier and a Symmlet level 4 wavelet transforms respectively as the sparsifying bases.

**Key Words:** ECG monitoring, Filtering, Detection, Compression sensing, Fourier transform, Wavelet transform, Symmlet.

1 **Introduction**

The electrocardiogram (ECG) is a widely used tool for the diagnosis of heart related diseases as it is non-invasive and provides information about the heart. Long term remote ECG monitoring is being used to monitor health of patients diagnosed with cardiac diseases so as to provide remedial health care.

Typically the patient wears an embedded wearable device with ECG sensors which acquire, store and transmit ECG data to a health center. The energy consumption of these devices has been an issue which severely restricts the usage of these devices effectively.

Different hardware, software and system architecture based solutions have been proposed to realize a low power ECG monitoring devices. Some of them are focused on processing the data and extracting event based information before transmitting as wireless data transmission requires considerable energy. Some solutions focus on the complexity and computational requirements of the algorithms for filtering and detection which drive processor and RAM requirements effecting hardware design.

Recently, compressive sensing [1] is being seen as a potential solution in many applications where the acquired signal is sparse. The ECG signal exhibits this property of sparsity and is seen as an application which can benefit from the use of compressive sensing [2 - 4]. The objective of this paper is to determine an architecture that can be employed with compressive sensing to realize a low power wearable ECG device and determine that reconstruction is possible at a given compression ratio that can result in reduced energy consumption.
2 SYSTEM ARCHITECTURE

Effect of system architecture on Energy consumption

ECG embedded devices are subject to constraints of weight, compactness and enough battery power to keep the patient mobile and non-interfering with day to day activities. Traditional remote monitoring systems acquire, store and transmit data to health/data monitoring centers where the data is analyzed and feedback is provided. Normal data acquisition requires a high sampling rate (Nyquist criterion) to faithfully capture information resulting in a lot of data that needs to be stored and transmitted. Storage and wireless data transmission requirements primarily determine the energy capacity of the embedded device. To reduce energy consumed during transmission, different architectures have evolved which do the data processing before transmitting and only send out event based data. However, storage requirements and more processing power are required. With compressive sensing the acquired data is reduced resulting in reduced storage and transmission load is reduced due to compression. All the above three described are presented in the block diagram shown in figure 1. Signal recovery and processing are offloaded to the health monitoring centers. Clearly, the approach of compressed sensing would result in low power devices provided signal recovery can be accomplished without loss of data.

![Figure 1- Different Architectures](image-url)
Figure 2 illustrates the system architecture of the embedded device employing compressive sensing for data acquisition and transmission of the compressed signal to health centers or other devices which will reconstruct the transmitted signal and have the necessary algorithms to perform denoising and QRS detection to generate analytics for feedback and remedial measures to patients.

Benefits and Requirements of Compressive sensing as applied to Long term ECG Monitoring

Compression Sensing is a Sparse Signal Processing Technique[1] when used for ECG measurement reduces total power consumption of the device by reducing sampling and amount of wireless traffic thereby providing the below benefits:
1. Reduced transmission power [2] (highest energy consumption in embedded sensing device) resulting in extended battery period.
2. Reduced requirements of bandwidth to transfer data.
3. Reduces data storage while retaining useful information.
4. Transfers processing load from the acquisition part to the reconstruction part and hence simplicity of measurement which is important when computational resources, acquisition time and sensor hardware are limited.

The below requirements should be taken care of when utilizing this method to realize the above benefits.

- Method works only for signals which are sparse.
- Reconstruction complexity and sensitivity to Noise determine the suitability of this method to the application under consideration even if the signal is sparse.
- The suitability of this method to acquire, transmit and reconstruct the ECG signal for R-Peak detection for the proposed new model.

3 COMPRESSION SENSING

Compression sensing methodology

Compressed sensing [5] solves the reconstruction of a sparse signal which contains a few nonzero elements, from its linear measurements, less than the number of unknowns. Many of algorithms have been developed to resolve this underdetermined inverse problem with sparsity prior on the solution. The below illustration in figure 3 summarizes the methodology involved in compressive sensing with measurement phase and reconstruction phase.

Figure 3 Compressive Sensing Methodology

Analysis to determine acceptable compression ratio
Analysis was first carried out by employing a random Gaussian matrix as the compression sensing matrix() and an Identity matrix as the sparsifying basis () to operate directly on the Time Domain signal with compression ratios (CR) of 10, 20 and 30% as this approach if successful will reduce the processing complexity in the reconstruction phase. Record 100 from the MIT-BIH database was used as the input signal.

The figure 4 shows results for 10% compression. A represents the original signal, B the compressed signal and C shows the recovered signal. It can be seen that the recovered signal is not representative of the original signal and some form of thresholding would need to be employed to detect the R-Peaks.

![Figure 4 10% CR on time domain signal](image)

Figure 5 shows recovered signal for 20% compression.

![Figure 5 20% CR on time domain signal](image)

Based on results obtained it can be concluded that only 10% or lower compression shows acceptable results which does not provide
significant energy consumption reduction and leading to the conclusion that the time domain ECG signal cannot be considered to be sparse.

Analysis was next carried out by choosing the Fourier transform as the sparsifying basis and a compression sensing matrix based on the inverse Fourier transform to operate on the transformed frequency domain signal with compression ratios of 10, 20 and 30. Results for 20% and 30% compression ratios are shown in figure 6 which show very good recovery results which can be used for QRS detection. Results for Compression ratios greater than 30% were not acceptable.

![Figure 6 30% CR with Fourier transform as sparsifying basis](image)

The wavelet transform as a sparsifying basis was evaluated next using a number of different orthogonal wavelet families. The wavelet based compression sensing matrices were generated by using a Matlab toolbox Wavelab850 toolbox (5) from Stanford University which can create quadrature mirror filters for different wavelets which can then be used with the identity matrices to generate sensing matrices. The results are tabulated in figure 7 where E is Good recovery, A is Acceptable Recovery and NA is not acceptable.
The Sym4 followed by db4 provided the best recovery with 40% Compression. Results for Sym 4 are shown in figure 8.

Figure 8 40% CR with Symmlet 4 as sparsifying basis

4 CONCLUSION

This paper illustrated a system architecture based on compressive sensing as a means to realize a low power ECG embedded device. Results obtained in the frequency domain show potential of the
compressive sensing technique to reduce energy requirements to up to 30% to 40% compared to traditional mode using Fourier transform and Symmlet 4 wavelet transform respectively as the sparsifying basis.

References


