Low Power Intelligent Wearable Cardiac Sensor Using Discrete Wavelet Compression

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***Abstract* - Claiming 17.1 million lives a year, cardiovascular diseases are one of the major causes of death in the world especially in rural India. Conventional ECG monitoring instruments are quite bulky and if we are able to miniaturize them, then they can be used to collect data in scenarios that were not possible with the traditional systems. The system proposed here describes a low cost, low power wearable wireless sensor which can be used for issuing early warnings of cardiac disease to doctors, who are mostly mobile or who are away from the patient's location. The knowledge of early symptoms of a cardiac disease will provide an opportunity for the doctor to deliver real-time instructions to a relative/care taker for giving urgent medical care to the patient. Power optimisation has been achieved by using wavelet based compression technique (DWT) and also different modes of operation based on the risk factor of the patient. An algorithm based on discrete wavelet compression for power optimisation is developed and it is simulated in MATLAB. The results obtained shows that this technique achieves a power reduction of 22%. The proposed system can be used to deliver better healthcare to rural India, where availability of experienced doctors is almost scarce compared to urban India.**

***Keywords*- ECG, noise, interference, power, filter, wavelet, DWT**

I. INTRODUCTION

Cardiovascular diseases are one of the biggest causes of death worldwide. However, over the last two decades, cardiovascular mortality rates have declined in many high income countries due to the advancements in healthcare industry. But it is not the case for low and middle income countries like India, Bangladesh etc. Cardiovascular diseases have increased at an astonishingly fast rate in these countries. According to World Health Organization (WHO) and the Indian Council of Medical Research (ICMR), India will be the heart disease capital by 2020. So if we are able to detect the symptoms of this disease at an early stage, proper medical care can be given to save lives.

The advancements in wireless sensor networks provide a new path for the real time monitoring of cardiovascular patients. So if we are able to integrate medical technology with wireless sensor networks (WSNs) then it will provide a way for the early detection of cardiovascular disease. The objective of this research is to develop a system which can: be attached to the human body for sensing the heartbeat, do an initial level of processing, and send a warning to the doctor once an abnormality has been detected. The analysis is done first in the sensor module and then it will be sent to the patient's mobile phone. Since it is a battery powered device power consumption has to be minimized. The proposed system could be used to detect cardiac arrhythmias like tachycardia, bradycardia etc which causes an abnormality in the heart rhythm.

The rest of the paper is structured as follows. Section II presents the existing systems used for ECG acquisition. Section III describes the architecture of the proposed wearable sensor. In section IV, the signal processing and wireless transmission techniques are described. Section V discusses about the wavelet compression technique used in the system. Section VI details the modelling of the average power consumption of the system. In section VII the results obtained by implementing the system are given. Finally conclusions are drawn in section VIII.

II. RELATED WORKS

Different research groups are working on developing a wearable ECG acquisition system for cardiac patients. A wearable health care system based on knitted integrated sensors is proposed in research paper [2]. The only drawback of the system is that the knitting and interconnecting processes of the conductive yarn increase the production cost. In our system we paid special attention to producing a low cost system.

A low power ECG recording system for long term monitoring of athletes is described in research paper [3]. It uses dry electrodes integrated on clothes. The disadvantages of this system are relatively high power consumption, low signal quality, large sensor size etc. A mobile phone based cardiac monitoring solution is detailed in paper [4]. The drawback of this system is that it is designed to be used only in home environment whereas the proposed system can be used for continuous monitoring of patient in any environments like hospital, home, in transit etc.

A wearable electrocardiogram (ECG) acquisition system is described in the research paper [5]. It is implemented with planar fashionable circuit board (P-FCB) based shirt. The disadvantage of this shirt is that we need to wear it whole time. However, in our eventual, proposed system the acquisition circuit will be implemented in the form of a small board which can be mounted on a belt and will be flexible to wear.

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In paper [6] the application of wavelet transform for ECG data analysis is described. This paper describes the different wavelets that can be used for data transformation and the compression ratio achieved with each of these wavelets. It gives a general idea about ECG data analysis using wavelets.

III. SYSTEM ARCHITECTURE

ECG signals in the range of milli volts and are susceptible to a large amount of interferences from different sources. So a great care should be given while designing an ECG acquisition sensor for eliminating this noise from the ECG signal. The first module in our proposed system is an ECG acquisition circuit for sensing the ECG signal and removing the artifacts to a maximum extend. The filtered signal will be then given to a processor module for digitization and initial level processing. The final stage is an RF transceiver module for sending the data to the next level of processing equipment. A block diagram representation of the whole system is shown in Fig 1. The different modules included in the hardware are described in the following sections.

A. Electrodes

Electrodes are used for sensing the bio-electric potentials caused by the contraction and relaxation of the heart. The electrodes will be attached at pre-determined locations in the patient's body. The proposed system uses a three lead ECG system. The electrodes act as transducers and convert the ionic flow from the body into electron current. This results in the development of an electric potential which can be measured by the ECG acquisition circuit.

B. Instrumentation Amplifier

The ECG sensor must be able to deal with the extremely weak nature of the ECG signal. Even if the signal is strong, it has a magnitude of less than 5mV. So the front end of the ECG acquisition circuit is an instrumentation amplifier which has the capability to sense low amplitude signals in the range of 0.05 - 5mV.

C. Noise Filtering

Designing the front end, of an ECG acquisition circuit, to have excellent noise reduction capability is a challenge. A high pass filter is used to remove the DC offset voltage and also to remove the baseline wandering occurring in an ECG signal. The noise frequencies which usually occur at frequencies higher than ECG signal frequency are eliminated using a low pass filter. Another major disturbance, for the ECG signal, is from the mains supply which is inhibited by a notch filter. There will also be some common mode noise generated from the patient's body which can be reduced using an ECG right leg driver.

IV. SIGNAL PROCESSING AND WIRELESS TRANSMISSION

The filtered ECG signal acquired, from the front end of the circuit, will be analysed in the sensor module using a suitable processor. The processor will be able to operate in different modes. These modes can be selected by the doctor according to the risk factor of the patient and the doctor will

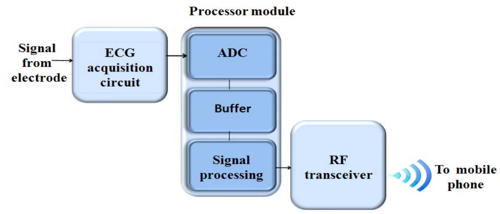

Figure.1. ECG acquisition system hardware

send the selected mode to the patient's mobile phone, using a remote trigger mechanism. From there, the message will be send to the ECG sensor module using Bluetooth communication. When a mode change message is received the sensor module can switch the mode automatically.

A schematic representing the proposed architecture is shown in Fig 2. A wavelet based compression technique, has been implemented, to reduce the power needed for sending via Bluetooth. The different modes designed are described below.

A. Mode I

Mode I is preferred for critical patients. In this mode, the sampling frequency will be high and the sensor will be sensing continuously. Here the data will be digitized and sending to the patient's mobile phone without any compression.

B. Mode II

In mode II, the data will be sent periodically, in an interval of a few minutes. Here compression will be applied to the data by using a single level discrete wavelet compression technique.

C. Mode III

In mode 3, the data will be analysed in the processor and sent to the mobile phone only if an abnormality is detected. The abnormality in case of arrhythmias will be detected by calculating the heart rate. The processing module will calculate the R-R interval in the ECG signal. From the R-R interval heart rate is calculated using the equation shown in (1) [7].

$$\text{Heart rate (beats/minute)} = \frac{60}{\text{R−R interval in seconds}} \quad (1)$$

For a normal human being, the heart rate will be (60-90) beats/ minute. Heart rates below 60 beats/minute are called bradycardia and heart rates above 90 beats/minute are called tachycardia. By calculating the heart rate these abnormalities can be easily detected and a warning message along with the ECG signal can be send to the doctor for further analysis.

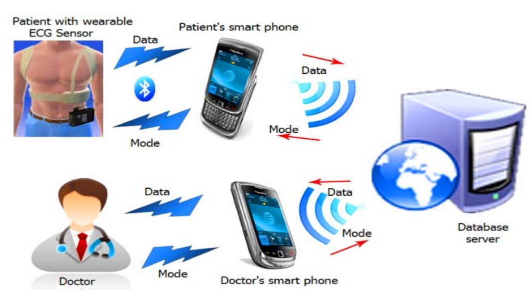

Figure 2. System Architecture

V. WAVELET BASED COMPRESSION TECHNIQUE

In wireless sensors, the most promising power reduction technique is to reduce the number of transmissions. The number of transmissions can be reduced by reducing the number of data items needed to send. The transformation technique that is used in our system is single level discrete wavelet transform (DWT).

DWT employs two sets of functions, called scaling function and wavelet function. The decomposition of the signal into different frequency bands is obtained by successive high pass and low pass filtering [8]. Let x[n] be the original digitized ECG signal and g[n] and h[n] be the impulse response of the high pass filter and low pass filter. The filtered signal will be down sampled by a factor of 2. The resultant filtered signals, from both the high pass and low pass filter, will contain approximately half the number of samples compared to the original digitized signal. A mathematical relationship showing the computation of DWT is given in equation (2) and (3) [8].

The high pass filtered signal will contain the detailed components of the signal and the low pass filtered signal will contain the average components. The original signal is now split in two by this filtering. The average components itself will give a satisfactory approximation of the signal. In other words, half the signals are unnecessary using the DWT. So here only the average components will need to be sent to the patient's mobile phone. These average components are then sent to the doctor's phone where the signal will be reconstructed. Reconstruction requires both the average and detailed components. As we will only have sent the average component we will replace the detailed component by zeros. With half the numbers of samples eliminated this DWT approach succeeds in a compression ratio of 0.5. Thus excellent power reduction is achieved with the number of transmissions reduced by half.

$$Yhigh[k] = \sum_n x[n] * g[2k - n] \quad (2)$$

$$Ylow[k] = \sum_n x[n] * h[2k - n] \quad (3)$$

We simulated the above result in MATLAB by using a sample ECG signal obtained from MIT-BIH database. The DWT of the signal was computed and then the signal was reconstructed using only the average component. The actual signal and the reconstructed signal resembled each other. The result obtained by compression is given in section VII.

VI. AVERAGE POWER CONSUMPTION

The sensor module consumes power mainly from the processes of sensing, processing, and transmitting via Bluetooth. The average power consumed by each of these processes is given in table1. For mode I there is continuous sensing, processing and sending of data. The power consumption is given by equation (4).

TABLE I. AVERAGE POWER CONSUMPTION

	Power consumption/hr
Sensing	3mW
Processing	1.8mW
Bluetooth transmission	90mW

$$P_{cons}(\text{mode I}) = P_{sen} * t1_{sen} + P_{proc} * t1_{proc} + P_{tran} * t1_{tran} \quad (4)$$

Here P_{cons} = Total power consumption
P_{sen} = Power consumed for sensing in 1 hour
$t1_{sen}$ = Sensing time in mode I
P_{proc} = Power consumed for processing in 1 hour
$t1_{proc}$ = Processing time in mode I
P_{tran} = Power consumed for transmission in 1 hour
$t1_{tran}$ = Transmission time in mode I

For mode II, the sensing, processing and transmitting will be done periodically. So the time taken for all these processes will be less and power consumption also decreases. Like mode I, the power consumption in mode II can be represented using equation 1. However, in mode II the time taken for a piece of data to be sensed, processed, and transmitted varies. For mode III, the power consumption depends on the frequency of occurrence of an abnormality. In mode III sensing and processing will be done continuously yet the data will be transmitted only on detecting an abnormality. This can be represented mathematically as in equation 5.

$$P_{cons}(\text{mode3}) = P_{sen} * t3_{sen} + P_{proc} * t3_{proc} + f(abn) * P_{tran} * t3_{tran} \quad (5)$$

Here f (abn) = frequency of occurrence of an abnormality

VII RESULTS AND VALIDATION

The analog front end was implemented using a NIELVISmx prototyping board and was tested by sensing a real human's ECG signal. When sensing an ECG signal, the electrodes are placed, on the patient's body, at the reference points by using an AgCl solution as the conducting material. The output obtained is as shown in Fig 3.

The sensed signal was then digitized and processed and can be sent to a patient's mobile phone. In WSN reducing the amount of data requiring transmission will reduce the amount of power consumed. DWT is a technique that can reduce the amount of data requiring transmission. In our MATLAB simulation, we investigated what part of the ECG signal was most necessary to preserve its actual data. The main information needed for diagnosing the arrhythmias are the R-R interval and the amplitude of the QRS complex. The average components of the ECG signal were found to be irrelevant and therefore did not require transmission. We found that if the detailed components of the ECG signal could be solely transmitted, they could be reconstructed (with 0 in place of average components) to produce a result accurately resembling that of the original ECG signal. Wavelet based compression technique (DWT) was completed on a sample ECG signal. The actual signal and reconstructed signal are given in Fig 4(a) and 4(b). The compression ratio that is achieved using this technique is 0.5.

Our results showed that using DWT can save power of approximately 22%, when ECG signal monitoring, provided the sensing interval is less than 10 minutes. This result of 22% was calculated using equation 4, where the power consumption of the system has been modelled. When the sampling frequency was set to 256Hz, the number of bits

$$P_{cons}(\text{mode I}) = P_{sen} * t1_{sen} + P_{proc} * t1_{proc} + P_{tran} * t1_{tran} \quad (4)$$

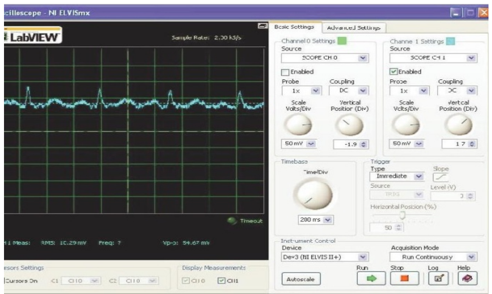

Figure 3. ECG signal obtained using analog front end

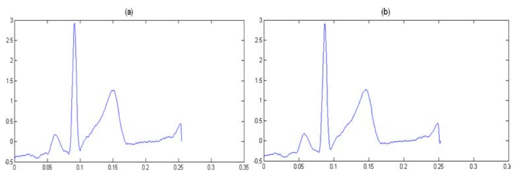

Figure 4. (a) Actual ECG signal (b) Signal reconstructed using only average component

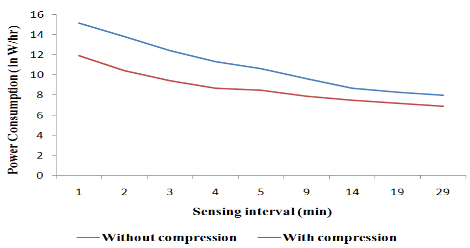

Figure 5: Power consumption comparison

required to transmit the data was reduced from 2048 to 1032. These results show a significant decrease in power consumption if DWT is used in ECG signal monitoring. DWT is effective at reducing power consumption when we are sending data at small intervals of time (Fig. 5); and the future of ECG signal monitoring will require the ability to send data in mainly small intervals of time. Though it is slightly irrelevant to the scenario being aspired to, if however, data is required to be sent in large intervals of time, this particular compression technique DWT will not help achieve a power reduction. This is shown in the Fig 5. Fig.5's graph shows the relationship between power consumption and sensing interval. From this graph it can be seen that as the sensing interval increases, the power saving reduces.

VIII CONCLUSION AND FUTURE WORK

This paper presents a low cost, low power ECG acquisition system which has immense application in the field of biomedicine for remotely monitoring a patient and for giving timely help. It has the capability to monitor patient in any environmental condition and send data to the doctor for further diagnosis and treatment. This takes advantage of a sensor node's capability to sense, process and transmit the data wirelessly. The power consumption is made low by efficient designing techniques and also at an algorithm level by reducing the amount of data needed to transmit using an efficient compression algorithm. With current ECG signal monitoring using expensive, high power consuming devices [7], the main contribution of this paper is in providing a method that reduces the power consumption cost effectively. In this research we introduce and align wavelet based compression technique (DWT) to ECG signal monitoring. We demonstrate how DWT is an effective tool to reduce the amount of data requiring transmission, in order to conserve power in ECG signal monitoring.

Also the system is made intelligent by making it capable to switch from one operating mode to another according to a remote trigger from the doctor. The doctor will select the mode according to the risk factor of the patient. This system will be especially useful for detecting the most commonly occurring cardiac arrhythmias like tachycardia, bradycardia etc. This system will be very useful for people in areas where the availability of specialized doctors are less. This will be a very effective solution to curtail the cardiovascular mortality rate in rural areas. The current system will be modified in future by adding some other options like GPRS for data transmission so that when the patient is in an area where connections are available, the data can be dumped directly to the Internet.

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