A Dual-PSoC based Reconfigurable Wearable Computing Framework for ECG Monitoring

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Abstract

We propose a reconfigurable framework using Dual-PSoC (Programmable System-on-Chip) based wearable computing system capable of ECG monitoring. Keeping in view wearability constraints involving comfort , ease and usability, we chose to use vectorcardiographic leads for minimizing the number of electrodes. It also helped to choose proper parameters to capture entire cardiac activity instead of relying only on Heart Rate Variability (HRV). Hidden Markov Model (HMM) combined with Timed Automata (TA) was used for modeling the ECG signal and extracting the features. A combination of Viterbi algorithm and Time-recurrent decision trees were used for classification of the input ECG signal and alert generation in case of abnormality noticed beyond threshold level. In all eight class models of heart diseases have been defined. Physikalisch-Technische Bundesanstalt Database (PTBDB) available at physionet.org was used for modeling. Data specific to these HMM models as well as decision trees were stored in the form of lookup tables in PSoC memory. As a part of the proposal, a belt embedded data acquisition unit has been envisioned for providing signals acquired from electrodes to PSoC. PSoC with wireless module was used for signal processing and further analysis in terms of classification and possible alert generation. The scheme envisages use of two PSoCs such that while first PSoc plays a role in data acquisition and processing ,second one shoulders the responsibility of classification and decision making.

1. Introduction

Cardiovascular diseases are one of the most life threatening diseases all over the world. The stressful, hectic and unhealthy life style leads to various heart related problems. Due to increased life expectancy population of elderly people is on rise that are prone to heart ailment. The early detection of symptoms and warning may prevent the person from further high risk of heart diseases. Negligence towards early signs of symptoms may lead to heart attack or even heart failure. Cost of medical treatment is increasing day by day. These are some of the reasons why researchers are focusing on prevention rather than treatment. If signs of heart ailment are read early then we can take proper care to avert further damage. One of such efforts is use of wearable computers.

Wearable computers are widely used as personal monitoring systems. The challenges for healthcare industry are to reduce health care cost, provide easy access to experts anytime or anywhere and shift the focus from treatment to prevention wherever possible. In health management, the individual is actively participating in the management process. Recording of physiological and psychological data of an individual in real-life conditions could be useful in management of chronic disorders, high blood pressure, diabetes etc.

2. Related work

One of the earliest physiological wearable computer was a Sensate Liner [1], combat uniform for soldiers. Signals from these sensors were acquired, processed and interpreted in a wearable, Pentium-type computer. Information thus acquired was then condensed and either stored in a storage device or transmitted to a suitable response unit for processing. Martin et al. proposed a wearable “ECG monitoring Device”[2] . In this case real time processing of heart’s electrical activity was done with digital signal processor TI C5410-100 DSP. A wrist worn Advanced Medical Monitor (AMON) with blood oxygen level sensor and pulse sensor was developed by Lucowitz et al under a grant in-aid from EU’s IST program [3]. A clinical device designed to free high-risk patients from the constraints of stationary monitoring equipments. alerts a doctor at remote place using a built-in mobile phone link in case of some abnormality. Ambulatory Blood Pressure Monitoring (ABPM) device [4] continuously monitored Ambulatory BP which is associated with organ damage and cardiovascular events and hence is more important than BP measured in clinical settings. Smallest ABPM device weighs 215 g (with battery) and size is 27x72x100 mm.

A novel SoC design of wireless sensor network ECG monitoring node was proposed by Xiao-gang et al [5] which was embedded into vest. Yang et al [6] proposed ECG monitoring system based on active cable and intelligent electrodes using configurable ECG chip. Deepu et al [7] described a highly integrated , low power chip for ECG signal processing. Marques et al [8] added blood pressure monitoring to ecg monitoring by acquiring PPG signals. Some projects described above acquired ecg signal and transmitted to smart phone or remote computer for further processing. In some projects signal processing is carried out but restricted only to QRS detection or HRV. Also Lifeguard of Stanford university for Astronauts and MyHeart from ETH Zurich are among few milestone projects in the history of wearable computers in physiological monitoring.

In this paper we propose a framework for a simple lightweight real-time on-line ECG monitoring wearable computer. ECG signal was modeled using HMM combined with TA. In case of deviation from predefined threshold values of some parameters, audio or visual alert was generated. This wearable computing unit will be embedded in clothes. While deciding the sensor position and other things Women convenience was considered who face otherwise inconvenience or embarrassment while recording ECG signal. Following sections provide the system overview, data acquisition and processing techniques, modeling of ECG signal using HMM combined with timed automata. Classification of the modeled signal and decision making based on that is also discussed. Level 2 alert transmission over web using mobile services is described in section 7. Conclusion and future scope is given in section 8 followed by reference.

3. System overview

An overview of the wearable computing system used to generate alerts using Timed HMM and Decision Trees is as shown in Figure 1.

The system includes support for sensor leads to acquire electrical activity of the heart, signal processing, feature extraction, Viterbi algorithm, classification and decision making unit to generate alert. While generating alert, current state vector was also considered with input vector.

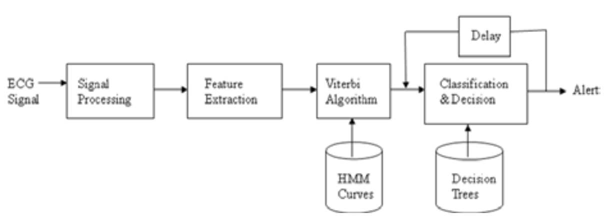

Figure 1. Block Diagram for Alert Generation [11]

To extract features, a four seconds window was considered. In normal ECG signal, this window has four to five beats. Average values of certain parameters of these beats were extracted and were fed to Viterbi network. Viterbi algorithm used these parameters to pick up the most likely state sequence, representing any of the class defined with the help of trained HMMs. Decision Trees were also trained to generate alerts according to the classification of signal using proper sequence of parameters. This alert was refreshed after every four seconds.

Three graded intensity alerts are generated. are of three types, having different intensity levels. Level 1 alert gives wearer a gentle warning about abnormality in the functioning of the heart. In more severe situation second level alert is sent to the wearer, his kin and registered doctor. This type of alert is discussed in section 8.

Third intensity level is generated in case of emergency. Location aware context needs to be added in it.

4. Data acquisition and processing

Unlike most other muscle innervations, excitation of the heart does not proceed from the central nervous system but is initiated in the sinoatrial (SA) node. SA node, a natural pacemaker, generates the electrical potential regularly which propagates through the specialized conducting tissue in a coordinated manner to produce an ECG complex consisting of P-QRS-T during one beat of the heart. This ECG complex indicates the total electrical events that occur during one beat. The P wave represents the atrial depolarization and repolarisation of atria while QRS-T complex represents ventricular activation depolarization and recovery (repolarisation).

An ECG is a graphic representation of electrical potential generated in the heart with surface electrodes. A 12 leads surface ECG is standard and conventional method to record the electrical activity of the heart from 12 different views in plane i.e. frontal and horizontal.

In continuous monitoring system one or more leads may be monitored. An orthogonal (EASI) Frank leads system is proposed in this paper in which few number of electrodes are required for recording of vectorcardiograph. The reason we chose Frank leads is that all the electrodes are in same transverse plane as shown in figure 2. The entire activity of the heart can be monitored without loss of information.

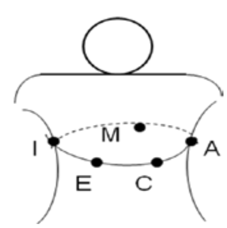

Figure 2: Frank Leads

Output of these leads was fed to first PSoC which processed the signal by configuring hardware circuitry consisting instrumentation amplifier, analog-to-digital converter(ADC) and filters.

Data generated by this PSoC was used by other PSoC to classify and generate alerts in abnormal situations.

5. Modeling, classification and decision

Hidden Markov Model (HMM) is used in biomedical signal process for signal segmentation, pattern recognition etc [5]. ECG signal is non-stationary signal. It has three main waveforms P-wave, QRS complex and T-wave. Segments are ISO (isoelectric line), PQ and ST and one QRS-T junction 'j . Each one of these waveforms and segments can be represented as a state. In addition to this, we have considered RR, PR, QRS, and QT intervals for modeling . For online monitoring we have chosen four parameters, RR interval which help to watch rhythm , QT interval , QRS interval and ST depression. The choice of parameters was based on the fact that these parameters capture atrial and ventricular activity of heart. HMM for one cardiac cycle is modeled as a time synchronized finite state machine which has distinct states switching from one state to another state. The observed output sequence of states, the duration of each state in which it remains is of special importance to carry out analysis. For that purpose we used a clock to find switching time from one state to another [10]. Figure 3 shows modeling details. Any deviation from predefined threshold values will lead to detailed analysis. Temporal and amplitude parameters were used to extract features from the signal because of the limited computing capability of wearable computer.

An HMM is a stochastic state machine, characterized by the following parameter set

$$\lambda = (A , B , \pi)$$

where A is the matrix of state-transition probabilities, B is the observation probability(O_i) and π is the initial state probability.

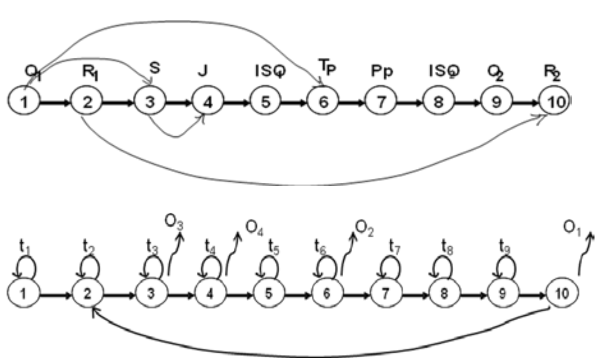

Figure 3: HMM and Timed HMM

Once the signal was modeled, a set of parameters were plotted to give an almost replica of the signal. In our case it is an image of the signal based on the states, we decided. This is called training of HMM. Like this, we can train any number of situations. In different cardiac ailments a peculiar pattern was seen. We modeled such different ailments and got number of models trained [9].

Since it is difficult to get subjects with various diseases, in a small town like ours, we had to rely on standard databases available on net. One such database, which suits to our requirement is Physikalisch-Technische Bundesanstalt Database (PTBDB), available at physionet.org website. This database has in all 15 signals simultaneously acquired including vectorcardiographic leads. About 550 records from 294 subjects (both healthy and with various heart diseases) are available. Using Matlab based HMM Toolbox seven different timed HMMs for different diseases were modeled plus one normal HMM was trained. Thus we got different learning curves which are stored in the form of look up tables in wearable computers. Standard Virerbi algorithm was used to find most likely sequence based on model and classify the signal. Time-recurrent decision-trees were constructed to take the decision and generate alert. Iterative Dichotomiser 3 (ID3) algorithm was used for construction and learning of decision trees [11].

6. Experimental setup

CY3209-ExpressEVK, PSoC kit from Cypress Semiconductors, was used for experimentation purpose. This board has four PSoCs, containing 8051 based processors, integrated high precision ADC. In addition to this potentiometer, accelerometer, socket for radio, LCD display also have been provided. For the purpose of wireless communication two artaflex AWP24S 2.4 GHz radios have been provided.

As the name suggests this is a programmable unit which carries out all the functions on single chip. Analog circuitry is considerably reduced here. If any new component is to be added or there is any design change, simply reprogramming is to be done. Calibration is easy to achieve, which is very important since no two persons have exactly same physiological condition.

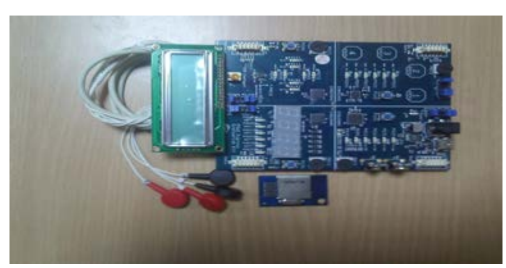

Figure 4: PSoC Kit

7. Alert transmission

As mentioned earlier, three level alerts were generated according to the predefined threshold level. Figure 7 gives an account of experimentation by us for transmission of alert over distance using web over services. Alert along with signal waveform was sent to wearer's mobile wirelessly. This mobile with FTP server in turn sent the signal to a central server. The signal was stored in a shared directory of the central server which is HTTP File Server (HFS). A graph was plotted and link of that graph image with timestamp was forwarded to doctor on his mobile. The image along with few parameters was made accessible to the doctor which was refreshed after every few seconds. It was observed that alert along with signal takes only 22 seconds to reach to the doctor.

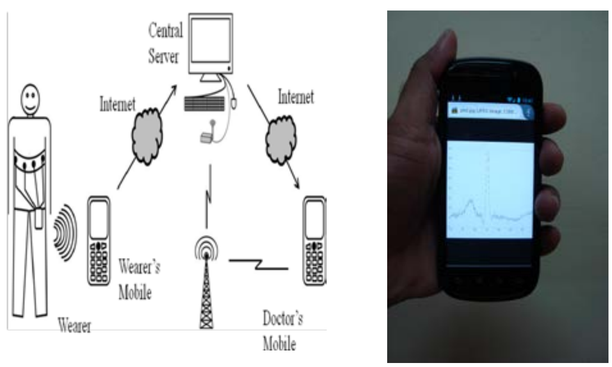

Figure 5. Transmission of alert over a distance

8. Conclusions and discussion

We propose a reconfigurable Heart-Guard wearable computing system in true sense which uses programmable system-on-chip. This system acquires real-time ECG signal. It not only samples data but processes it and takes decisions unlike other ECG monitors or Holter device. This computer can well be embedded in clothes or fabric. It is suitable for women and especially Indian women due to their style of dressing.

There are quite a few issues which need to be addressed before the final architecture is evolved. Detailed modeling using timed automata HMM for off-line analysis is to be carried out, where we have to increase the number of states to take accurate decision. Battery power is a main concern. Suppression of false alarms is a challenge, which can be achieved by studying correlation between the parameters. The electrodes used are non-invasive but must be placed on skin with the help of gel or so. This causes skin irritation or allergy in few cases. We are looking for dependable, non-contact wireless electrodes. PSoC kit used for experimentation has four processors. We require only two processors which will reduce size of the PCB by half. We plan to use flexible PCB so further inconvenience is minimized. Security, loss of information while transmitting are some of the issues need to be focussed.

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