AN ENERGY EFFICIENT ECG SIGNAL PROCESSOR FOR WEARABLE ECG DIAGNOSTIC SYSTEM

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by

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Certificate

This is to certify that the thesis entitled **"An Energy Efficient ECG Signal Processor for Wearable ECG Diagnostic System"**, being submitted by **Mr. Sanjeev Kumar Jain** for the award of the degree of **Doctor of Philosophy** to the **Department of Electrical Engineering, Indian Institute of Technology Delhi**, is a record of bonafide work done by him under my supervision and guidance. The matter embodied in this thesis has not been submitted to any other University or Institute for the award of any other degree or diploma.

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Abstract

Existing ECG monitoring and diagnostic devices detect cardiovascular diseases but are available only in hospitals. Recently, wearable ECG monitoring and diagnostic devices are proposed for cardiovascular disease detection. This way, cardiac patients can be monitored without staying in hospital for long time. The figure of merit of a wearable ECG monitoring and diagnostic device is its size, its accuracy, execution time and energy dissipation. In the early deveopment phases of a wearable ECG monitoring and diagnostic device, figure of merit is its accuracy. The ECG signal processing algorithms with high accuracy are slower and leads to higher energy dissipation. Therefore, there is still a need of an algorithm with low computational load and high accuracy. Presently, the focus has been shifted to improve energy dissipation. In order to further improve execution time and energy dissipation, the ECG signal processing is carried out in application specific integrated circuits (ASICs). Another advatnage of ASIC is its small size. Therefore, we can achieve high figure of merit for a wearable ECG monitoring and diagnostic device if we implement an ECG signal processing algorithm with low computational load and high accuracy in ASIC.

The existing ASICs or ECG signal processors detect QRS complex peak location, P wave peak location, T wave peak location, QRS complex start location and QRS complex end location. In order to detect bundle branch block and hypertrophy, we need to detect QRS axis, R wave peak value, Q wave peak value, secondary R wave peak value, S wave peak value, R wave duration and S wave duration. We need

P-R duration to detect AV block. Also, the existing ECG signal processors do not detect ST segment values and Q wave duration to detect various phases of myocardial infarction. Therefore, there is a need of an energy efficient ECG signal processor which detects P wave, QRS complex, ST segment and T wave parameters. This way, majority of the cardiovascular diseases can be detected in a wearable ECG diagnostic system in a similar way the existing ECG diagnostic devices detect them in hospitals.

In this thesis, we have presented a novel algorithm based on forward search for ECG signal processing and implemented in application specific integrated circuit (ASIC) for QRS complex related cardiovascular disease diagnosis. We have evaluated our algorithm using MIT-BIH arrhythmia database and achieve sensitivity of 99.86% and specificity of 99.93% for QRS complex peak detection. To detect cardiovascular diseases related to QRS complex, data from six ECG leads is required. In this thesis, Physionet PTB diagnostic ECG database is used for QRS complex related disease detection. A QRS ASIC for cardiovascular disease detection is fabricated using 130-nm CMOS high speed process technology. The area of the ASIC is 0.5 mm^2. The power dissipation is 86.028 μW at the operating frequency of 4 kHz with a supply voltage of 0.6 V. The output from the QRS ASIC is fed to our Android application that generates diagnostic report and can be sent to a cardiologist via email. Our QRS ASIC result shows average failed detection rate of 0.16% for six leads data of 290 patients in PTB diagnostic ECG database. We have also implemented a low leakage version of our ASIC. The ASIC dissipates only 41 pJ with a supply voltage of 0.9 V.

We extended forward search based algorithm to develop a new disease diagnostic algorithm that detects P wave, ST segment and T wave besides QRS complex. This disease diagnostic algorithm is verified for Physionet QT database. The sensitivity and specificity of P (T) wave detection are 98.91% and 91.07% (99.97% and 97.76%) respectively for QT database. We achieve 100% sensitivity and specificity for QRS complex detection for QT database. A PQRST ASIC based on our disease diagnostic algorithm is fabricated using 130-nm CMOS low leakage process technology. The area of the ASIC is 1.21 mm^2. The power dissipation is 125 nW at the operating frequency of 4 kHz with a supply voltage of 0.9 V. We detect hypertrophy, bundle branch block, arrhythmia, various phases of myocardial infarction, AV block, hypocalcemia and hypercalcemia using P wave, QRS complex, ST segment and T wave parameters. The disease detection criteria for these diseases are coded in our android application. This android application reads outputs of PQRST ASIC and generates diagnostic report. We obtain high accuracy of disease detection in Physionet PTB ECG diagnostic database and St. Petersburg institute of cardiological technics 12-lead arrhythmia database. Our proposed PQRST ASIC achieves high figure of merit (small size, high accuracy, small execution time and low energy dissipation). Our PQRST ASIC together with android application is the most suitable for a wearable ECG monitoring and diagnostic system.

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