CUDA based Implementation of automated ECG diagnostic QRS-complex using curve length transform

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[Abstract]

Countless efforts have been made to analyze and classify ECG signals belonging to various heart problems, in which QRS complexes are an important source of information. Applications for processing QRS complexes is time-sensitive and data-intensive due to quickly increasing problem domain sizes and advancing experimental techniques. We proposed a massively parallel approach on GPGPU to address this research challenge. It accelerates the speed of calculation of ECG to 10 times as compared with the serial algorithm. It is concluded that a GPU-based parallelization is convenient and effective way to speed up the automatic detection of QRS complexes in ECG.

[Introduction]

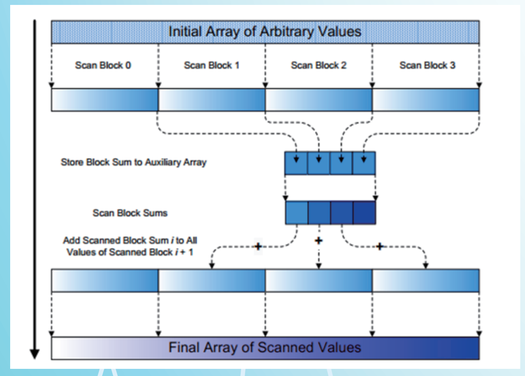
The electrocardiogram (ECG) is a recording of the surface potential created by the electrophysiological processes of the cardiac cycle and used diagnostically by cardiologists and general practitioners.

Current automatic detection of QRS complexes have gotten quite accurate but are slow on big data.
Implementation and performance test are conducted in an Intel PC equipped with GPU Tesla T10.

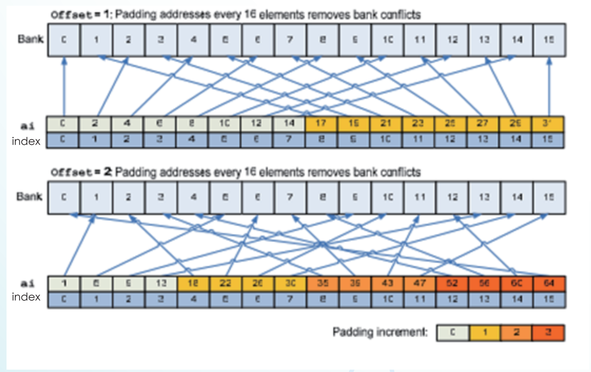
Curve length transform is a novel algorithm to detect onset and duration of QRS complexes.

Parallel prefix sum, also known as a parallel Scan, is a useful building block for many parallel algorithms including sorting and building data structures. We have implemented it in curve length transform to speed up the detection process.

[Parallel Prefix sum with CUDA]



[performance of a sum scan on a large array in one grid]



[performance in one block (Addressing with Padding)]

```
int ai=offset*(2*index+1)-1;    int bi=offset*(2*index+2)-1;
ai+=ai/NUM_BANKS;               bi+=bi/NUM_BANKS;
temp[bi]+=temp[ai];
```

[Curve length transform]

>> We use a second order recursive low-pass filter to suppress low frequency components.

>> if y(t) is continuously differentiable over the time interval[a, b], then the of y(t) in this time interval equals a bounded value L:

$$L = \int_a^b ds = \int_a^b \sqrt{1 + (\frac{dy}{dx})^2}\, dt$$

>> The curve length transformation of function y=y(t) over the interval[t-w, t] is defined as:

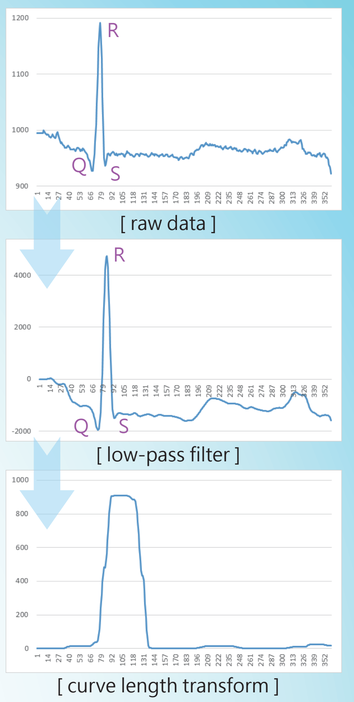
$$L(w, t) = \int_{t-w}^{t} \sqrt{1 + (\frac{dy}{dt})^2}\, dt$$

w is the duration of the time window.

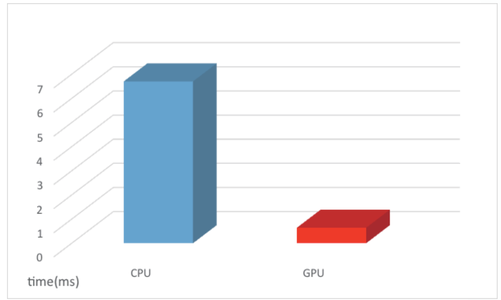
>> The discrete form is as follows:

$$L(w, i) = \sum_{k=i-w}^{i} \Delta S_k = \sum_{k=i-w}^{i} \sqrt{1 + (\frac{\Delta y_k}{\Delta t})^2}\, \Delta t = \sum_{k=i-w}^{i} \sqrt{\Delta t^2 + \Delta y_k^2}$$

>> Adaptive thresholds are applied to the length signal to determine the onset and duration of the QRS complex.



[Achievement]



The parallel computing for the automatic detection of QRS complexes in ECG signals achieves an acceleration of 10 times compared to the serial algorithm.

[Contribution and Outlook]

Cardiovascular diseases (CVDs) are the number one cause of death globally. More people die annually from CVDs than from any other cause. The number of people who die from CVDs will increase to reach 23.3 million by 2030. Automatic detection of abnormal beats in ECG signals will help more CVD patients to get sequential treatment from doctors. Now a huge number of ECG signal data is a heavy burden for the doctors. Accelerating the whole process of the automatic detection and classification of ECG signals is significant to the treatment in the field of CVDs.

Using prefix scan sum in the length transform have greatly improved the detection of QRS complexes in ECG signals. But it is only one part and has limited influence on the whole process.

Our next challenge is to combine CUDA with following tasks in the diagnosis of abnormal beat to speed up the whole process.

[Reference]

Zong W, Moody G B, Jiang D. A robust open-source algorithm to detect onset and duration of QRS complexes[C]//Computers in Cardiology, 2003. IEEE, 2003: 737-740.
Harris M, Sengupta S, Owens J D. Parallel prefix sum (scan) with CUDA[J]. GPU gems, 2007, 3(39): 851-876.
Deng Z, Chen D, Hu Y, et al. Massively parallel non-stationary EEG data processing on GPGPU platforms with Morlet continuous wavelet transform[J]. Journal of Internet Services and Applications, 2012, 3(3): 347-357.