Real Time Heart Rate R-R Interval Monitoring

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Abstract:- *Electrocardiogram gives important information about human health condition. In order to achieve accurate measurements, side effects, such as noise, voltage drift, mains hum must be extruded. This article describes an algorithm for fast and precise heart rate interval detection implementation in microcontroller.*

The system is based on STM32F4 microcontroller which samples data from AD8232 chip. Data is filtered and processed. From processed data decisions are made to find R peak locations.

Key Words: **ECG signal, R peak detection , adaptive threshold, variance , STM32F4 microcontroller**

1. INTRODUCTION

Human heart rate gives important information about heart condition. Electrocardiogram (ECG) represents electrical activity of human heart. ECG is composite from 5 waves - P, Q, R, S, T. Heart rate interval is calculated from R peaks. The main problem of digitalized signal is interference with other noisy signals like power supply network 50 Hz frequency and breathing muscle artefacts. These noisy elements have to be removed before the signal is used for next data processing for R-R interval detection. Digital filters and signal processing must be designed very effective for next real-time applications in embedded devices

2. ALGORITHM REVIEW

Heart rate frequency can be detected from ECG signal by many methods and algorithms. Heart rate frequency can be calculated using the energy signal thresholding as showed in [1]. The threshold is used for finding the signal parts where R-peaks are situated. The peak detector in this algorithm is not used. Firstly, time indexes of samples higher than the threshold are found. After that, the algorithm computes differences between time indexes. Only samples with time index differences higher than the minimal physiological heart period are selected as the R-Peaks.

ECG peaks can be highlighted using integrator filter firstly. This approach is described in [2]. Energy signal is smoothed by this filter. Moreover, the energy signal envelope is made. The peak detector is used to find the peaks in the signal envelope

Some algorithms for heart rate detection are based on QRS complex detection and heart rate is computed like distance between QRS complexes. QRS complex can be detected using artificial neural networks, genetic algorithms, wavelet transforms or filter banks [3]. The direct methods for heart rate detection are ECG signal spectral analysis and Short-Term, Autocorrelation method. It is possible to detect R-R peaks using adaptive threshold.

The well-known Pan and Tompkins method, which is a benchmark in the R peak detection field, is based on the slope, amplitude and width of the ECG signal [4]. After a pre-processing phase aimed at removing the noise, smoothing the waveform and amplifying the QRS slope and width, adaptive thresholds are applied to the signal in order to localize true positive R peaks. This method optimizes the decision rules by the performance test of three estimators (mean, median and an iterative peak level) for the adaptive threshold placing. With the aim to implementing a real-time system which is able to monitor the heart rate. An adaptive thresholding-based ECG R peak detection procedure which combines the ECG segmentation method with the adaptive thresholding is indicated.

3. SIGNAL ACQUISITION

Experiment is carried using ECG signals from database and sampled from real persons. Database used is *physionet* ECG database specified by the current American National Standard for testing various devices that measure heart rate ANSI/AAMI EC13 Test Waveforms [6]. Recordings. These include both synthetic and real waveforms sampled at 720 Hz with 12bit resolution. For signal acquisition on real persons data acquisition system was designed. It is based on fully integrated single-lead ECG front end chip AD8232. Output of the chip is analog signal in range from 0 to 3.3 V. Output is sampled at 6 kHz sampling frequency. High sampling frequency is used to achieve better precision. Many devices in market use sampling frequency up to 500 Hz. Main goal of Matlab debugging is to later implement algorithm in microcontroller. Signals from *physionet* differs from acquired with hardware in amplitude and sampling frequency. Interpolation of 8 is used to make signal more similar with one acquired with hardware. Example of one signal from *physionet* database is showed in 1 figure.

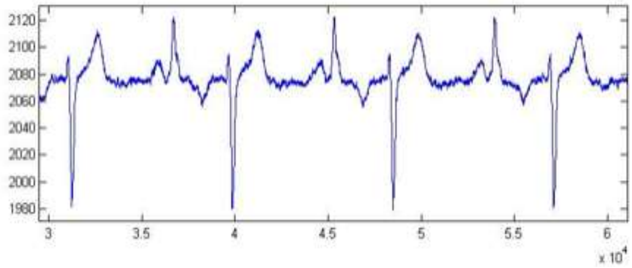

Figure 1. Interpolated half synthesised ECG signal

For this kind of signal there are no drift, noise level is small. R peaks can be found from raw signal using adaptive thresholds and simple logic: if sufficient time has passed after last known peak and signal level is bigger than adaptive threshold, then we can compare new value with previous and check if amplitude is higher. If maximum value was updated and new upcoming values are descending, then it is stated what last updated maximum value was R peak. According to number of points between two identified peaks and sampling rate interval can be calculated. For implementation in real time embedded system holds last find peak and searches for new one. After new peak is detected R-R interval is calculated and last known peak updated with new value.

Problems occurs then signals are noisy or offset drift is very large. Example of registered complicated signals can be seen in figure 2. Other problems may be bad electrode contact with skin. Mains voltage also can influence signal. For smoothing the signal low pass filter is used. Filter used is Chebyshev type 2 4-order IIR filter with stopband frequency at 250 Hz, stopband attenuation -80 dB, cut-off frequency 42 Hz. Filter frequency response is shown in figure 3.

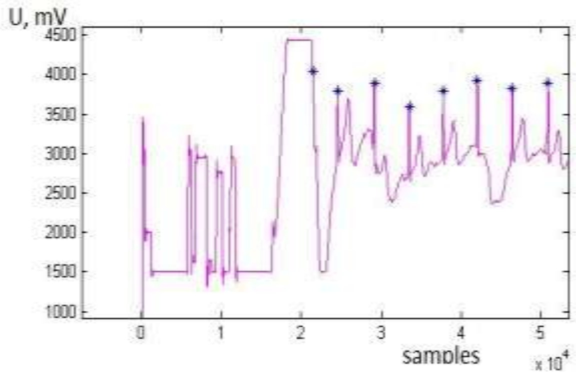

Figure 2. ECG signal with corrupted start

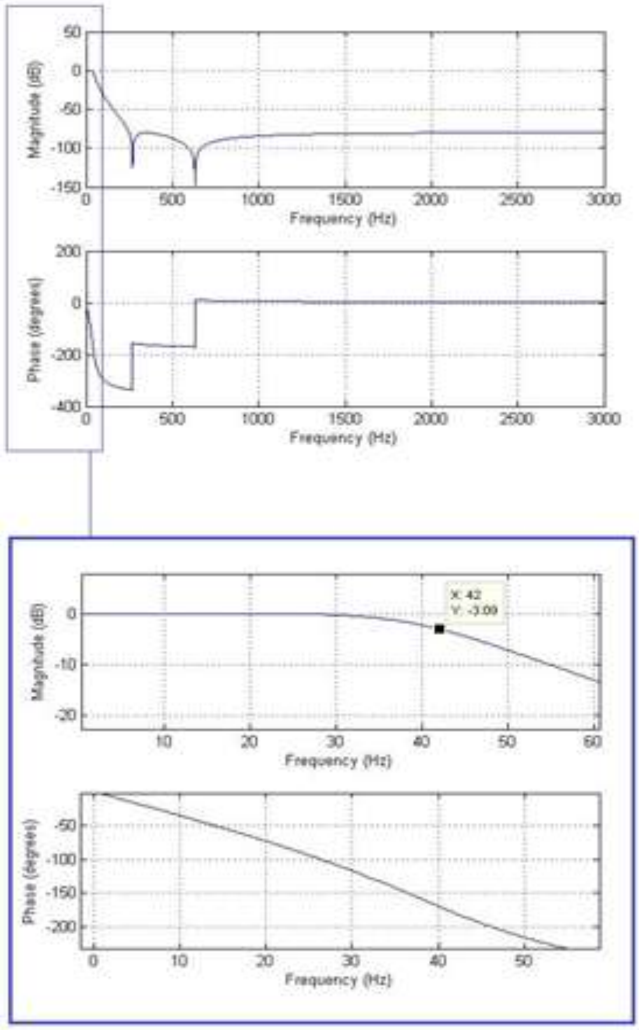

Figure 3. LP filter frequency response

4. ALGORITHM IMPLEMENTATION

Filtered signal can be used for peak information extraction. Simplified algorithm is shown figure 4.

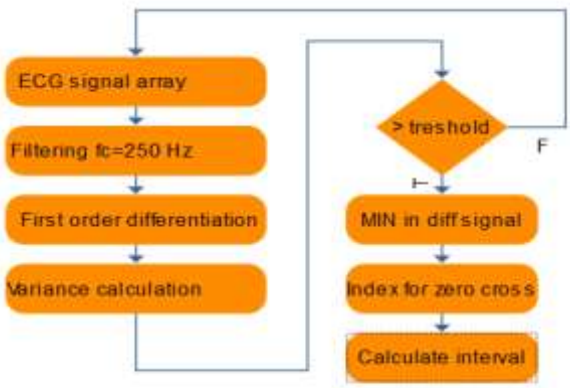

Figure 3. Proposed algorithm simplified structure

First step is differentiated signal calculation from 32 values by formula:

$$x(n) = x(n) - k(n-32) \qquad (1)$$

and filtered differentiated signal with moving average filter:

$$D_{filt} = \frac{\sum_{n=1}^{k} D(n)}{k} \qquad (2)$$

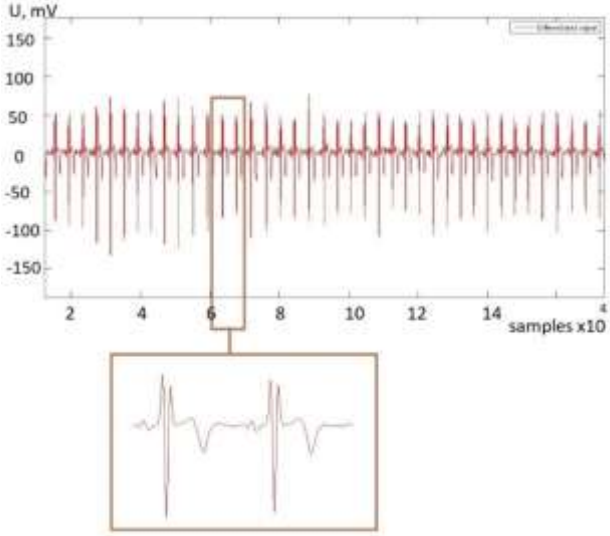

Figure 4. Differentiated ECG signal

Result of differentiation is showed in figure 4. In differentiated signal important parts are local minimums. Next step is variance calculation using differentiated signal and filtered differentiated signal:

$$v(n) = (k-1)v[n-1] + \frac{(D(n) - D_{filt}(n)^2)}{k} \qquad (3)$$

Parameter k = 40. Adaptive threshold is calculated using variance filtered with moving average filter from 10000 values and multiplied by constant:

$$V_{ths} = \frac{\sum_{n=1}^{10000} V(n)}{k} . 3 \qquad (4)$$

Calculated variance and threshold value is shown in figure 5. Multiplication by factor 3 is necessary to increase SNR.

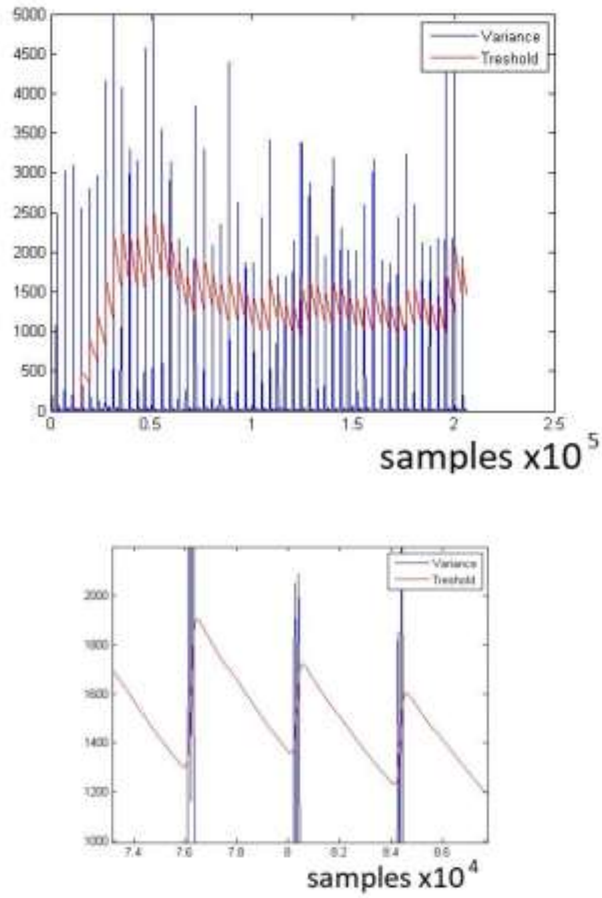

Figure 5. Calculated variance and variance threshold

When new variance values are bigger than variance threshold R-peak search begins. Usually ECG signal at that time is reaching R peak value. Delay of 200ms is implemented for acquiring more data points. After delay RS interval in ECG signal is over and T wave is started. First in differentiated signal latest minimum is found. Then values in array are checked backwards until differentiated signal reaches zero and becomes positive. Index in differentiated signal is index in ECG filtered signal R peak, additional signal delay from differentiation and filtering must be compensated. Result is shown in figure 6.

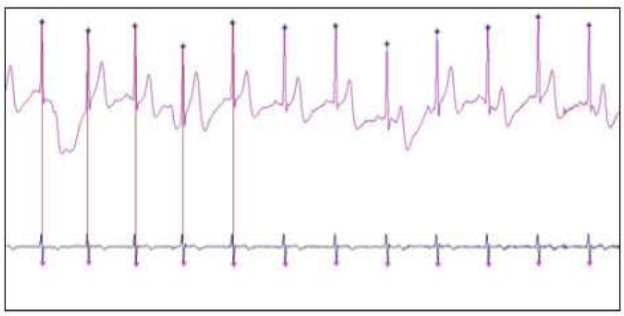

Figure 6: Connection between differentiated signal and filtered ECG signal

5. ALGORITHM TESTING

Implemented Matlab algorithm was tested with 6 real people ECG signals and 6 signals from database mentioned earlier. Results are summarised in table 1. Correctly found peak means peak found and marked in correct place in signal, incorrect means point which is not R peak was marked.

Nr.	Signal source	Total R peaks	Found correct	Found incorrect
1	Database	58	57	1
2		58	58	0
3		22	22	1
4		17	11	0
5		17	11	2
6		22	4	0
7	Real person	76	76	0
8		120	120	0
9		48	48	2
10		49	48	1
11		77	74	2
12		119	118	1

Table 1. Algorithm test results

Algorithm works better with signals from real people because analogue filter is fitted. Some signals from database are very noisy and algorithm misses to detect R peaks. On the other hand, signals from real people contains amplitude saturation and false peak detections occur.

6. MICROCONTROLLER IMPLEMENTATION

Main goal of real time heart rate algorithm is easy implementation in microcontroller. For better precision sampling rate of 6 kHz is used. It is important to take into consideration the processing speed of the MCU. Algorithm was tested with STM32F4 family microcontroller clocked at 86 MHz. Filtering is achieved using CMSIS DSP library for IIR lattice filters. Filtering is achieved in blocks of 32 data samples, so filtering function is required every 32 ADC samples. ADC measurement frequency is 6 kHz so time between samples is 166.7 µs and the filtering function requires 150µs respectively. Filtering function does not overlap with new measurements, but decision logic also takes time. Some ADC samples get lost during signal filtering and decision making. Signal array to keep 3 seconds signal (18000 elements) is used to keep track of raw ECG signal. This circular array is updated inside interrupt routine, so there are no lost samples. Decisions for peak detection are made with filtered signal. Found peak in filtered signal is converted to peak in raw signal, so timing is very precise.

Decision logic finds minimum local peak in differentiated signal. From this peak going backward search for point where differentiated signal passes zero is found. This point corresponds to R peak in ECG filtered signal. Because ECG signal was filtered and delay is different for different frequencies, found peak is not correct. Instead window of 33 ms is applied to unprocessed ECG signal, In that window maximum value is found. This new value is correct R peak. Using last recorded R peak index interval is calculated from array elements indexes:

$$Rint = New - Old \quad (5)$$

After successful interval detection new index is marked as old index and after 200ms R peak detection continues.

7. CONCLUSION

Fourth order Chebyshev filter and first order differentiation are considered enough for signal processing. Variance is a good parameter for peak search start, but it is very important to make an adaptive variance threshold, to keep track on the heart rate when signal is cut on and off. Microcontroller at fast discretization might lose samples, so array of raw samples must be included. Decision logic marks point where to start R peak detection. After R peak location is found interval is calculated.

8. REFERENCES

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