# Device for Long Term Measurement of Heart Rate

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## ABSTRACT

In this contribution, a device for long term measurement of heart rate is described. The device is created based on development kit STM32-Primer2. Heart rate frequency is calculated from selected electrocardiograph lead from the external module. The device allows simultaneous recoding of acceleration which makes is appropriate for physical activity detection of the test subject. The recorded data is saved on a memory card as signals in raw form, which can be used for subsequent processing in various research areas. Modular solution is suitable for connection of other modules. This device is designed for research and educational purposes in the field of medical devices and signal processing.

## Categories and Subject Descriptors

B.4.0 [**Input/Output and Data Communications**]: General
I.5.4 [**Pattern Recognition**]: Applications, Signal Processing

## General Terms

Measurement, Algorithms.

## Keywords

Acceleration, stress test, biofeedback, STM32-Primer2.

## 1. INTRODUCTION

Long term measurement of heart rate is the most common way for vital functions monitoring. Much information of cardiac anomalies can be obtained from this measurement. Long term monitoring is used especially for psychical and physical stress testing. Recording of acceleration together with heart rate is suitable for movement detection of the tested person during physical stress tests.

Heat rate frequency calculation is possible from signals which could be measured by various methods. The most frequently used signals in clinical practice are electrocardiogram (ECG), pletysmogram, pulse oxymetry curve or blood pressure curve. But there are possibilities for measuring of the heart rate from other signals.

Phonocardiogram is the signal of cardiac echos which origins in cardiac valves and chamber walls activity. Balistocardiogram is the signal measured by tensometric sensors placed in the patient's bed [1]. Heart activity is clearly displayed in the signal that can be measured after the patient's body is placed in magnetic field. This field generates eddy currents based on tissue impedance. These currents create new magnetic field. The induction of this field is detected and processed by special circuits and filters. Measured signal is the output of these circuits [2]. If an optical fiber is inserted in the bed's mattresses, its length is changed by heart and breathing activity. By using optical interferometer, it is possible to measure the length changes and to obtain signal that includes information about heart activity [3].

These signals are not suitable for long term measurement of heart rate because implementation of their measurement system is not possible to a portable device.

Many other devices could measure heart rate frequency and monitor basic vital functions, for example heart monitors for sports. The disadvantage of these devices is that they don't allow recording the signal. And if they allow recording the signal, it's not possible to export the data for future processing, because they are usually locked by their manufacturer (for example ECG Holter BTL-08).

The created device provides raw signals appropriate for further processing. The device is very simple and portable and therefore is suitable for stress tests and biofeedback. Modular solution allows connecting other modules which are intended for measurement and transmission of biosignals mainly in telemedicine applications. It is possible to use the system also in education as a model of telemetry system.

## 2. DEVICE HARDWARE DESCRIPTION

The device consists of three main parts (Fig.1), which are as follows: the external modules for ECG signal measurement, the extension board for development kit and the development kit STM32-Primer2.

### 2.1 External modules

Two external modules for ECG signal measurement were developed and realized in this project. The first module is a 3-electrode module dedicated to measure the signal from lead I. It was designed based on the circuit's schemas in article [4, 5].

The second module was designed according to the circuit schema of a professional electrocardiograph [6]. With this module it is possible to measure the signals from leads I, II, III and V1 using 5 electrodes. The output signal lead is selected by multiplexor.

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## 2.2 Extension board

The development kit was equipped with an extension connector. On this connector, unused peripheral microprocessor pins and supply voltage from kit battery are accessible. The extension board is connected to this connector. The board consists of a connector for connecting external modules, pull-up resistors and power circuits for external modules.

## 2.3 Development kit STM32-Primer2

The development kit STM32-Primer2 was selected for this project. The kit contains 32-bit microprocessor ARM CORTEX STM32F103BVET with maximal clock frequency 72 MHz. The device uses especially these kit components: LCD display, accelerometer, micro SD card slot and connector for extension board.

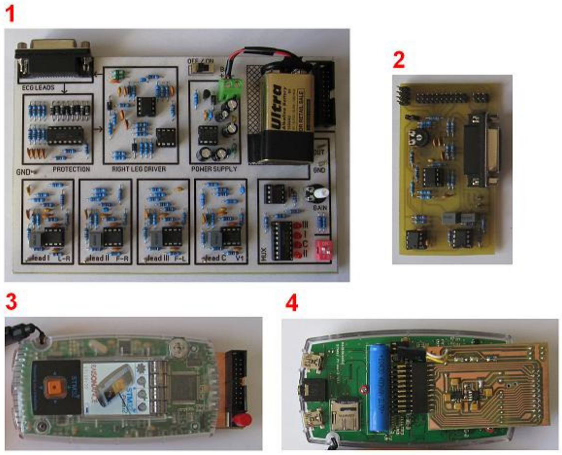

**Figure 1: Device main parts: external modules (1, 2), development kit (3), extension board inserted in development kit (4).**

## 3. DIGITAL SIGNAL PROCESSING

Digital filters for ECG signal processing has been designed in Matlab. In Figure 2the raw signal is displayed. The signal was measured on the external module using measuring card.

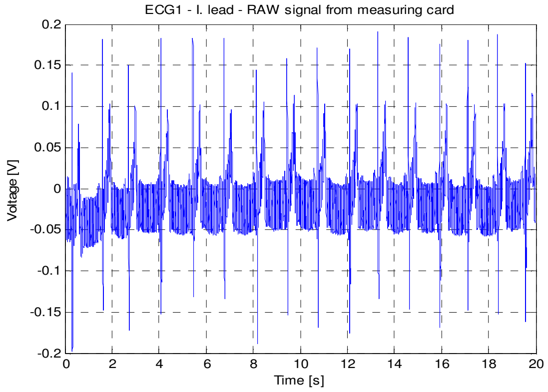

**Figure 2: Raw signal measured by measuring card.**

This signal was used for digital filters designing and testing. Block schema of signal processing and digital filters network is shown in the Figure 3.

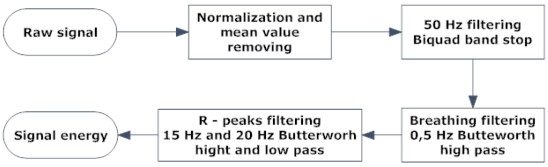

**Figure 3: Digital signal processing and digital filters block schema.**

At the beginning, the mean value was removed from signal and signal was normalized for unit maximum amplitude. The first filter removed the network interference at 50 Hz frequency. This filter type is biquad band stop. Baseline wander was provided by means of the next filter. This filter is second order Butterworth filter set to frequency of 0.5 Hz. This filter is usually used in professional ECG filtering applications. The signal filtered by these filters is shown in the Figure 4.

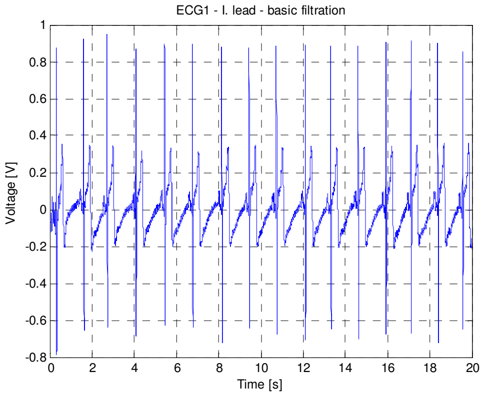

**Figure 4: Signal after network 50 Hz and baseline wander filtering.**

After the basic filtering, the R-peaks are detected from ECG signal. The signal is filtered by high pass and low pass Butterworth filters with cut-off frequencies 15 Hz and 20 Hz. Both filters are fourth order because of computing time in microprocessor. These filters were selected because it has better results than one band pass filter. After this filtering the signal energy (1) from voltage is calculated.

$$E(t) = u(t)^2 \tag{1}$$

Threshold is used to find signal parts where R-peaks are situated. In the Figure 5 it is depicted energy curve which is made from signal by R-peaks filtering.

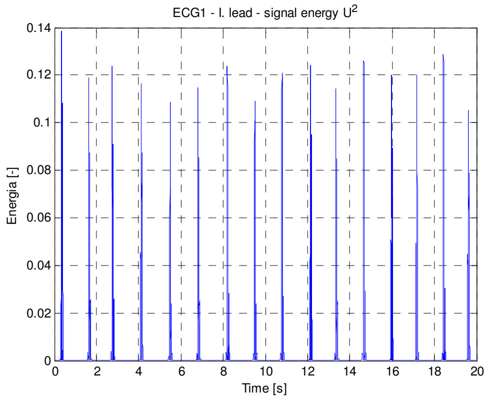

**Figure 5: Signal energy after R-peaks filtering.**

# 4. HEART RATE CALCULATION

In Matlab three algorithms were designed. These algorithms enable to calculate heart rate frequency from the signal energy. All three described algorithms were used on same signal. It means it is possible to compare the results and to choose the best algorithm.

## 4.1 Signal energy autocorrelation function

The first algorithm calculates heart rate frequency using autocorrelation function on signal energy. Peaks in autocorrelation function are highlighted by integrator filter. The peaks are extracted from autocorrelation function by peak detector. In the Figure 6, autocorrelation function, peaks and computed heart rate frequency are displayed.

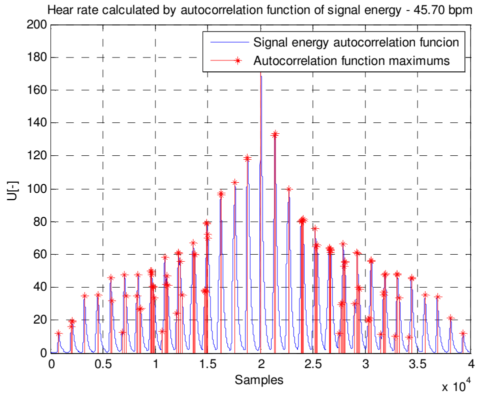

**Figure 6: Autocorrelation function of signal energy.**

## 4.2 Signal energy thresholding

The second algorithm computes heart rate frequency using the signal energy thresholding [7, 8]. The threshold is computed according the equation (2) which was derived empirically.

$$TH = 2 \times \bar{E}(t) \tag{2}$$

The threshold is used for finding the signal parts where R-peaks are situated. The peak detector is not used. Firstly, the algorithm finds time indexes of samples that are higher than the threshold. Then the differences between time indexes are computed. Only samples with time index differences higher than the minimal physiological heart period are selected as the R-Peaks. In the Figure 7 signal energy, threshold, R-peaks timestamps and the calculated heart rate are displayed.

## 4.3 Peaks in signal energy envelope

The third algorithm uses the integrator filter first. This filter smoothens the signal energy and highlights the R-peaks. The filter makes an envelope of the signal [9]. Then the peak detector is used. The detector finds the peaks in the signal envelope [10]. Heart rate frequency is computed from R-R intervals. If the interval between two R-peaks is lower than the maximal physiological heart rate, the next R-peak is taken. It prevents failures caused by artifacts in signal from occurring.

Signal energy smoothed by integrator filter, R-peaks timestamps and calculated heart rate are shown in the Figure 8.

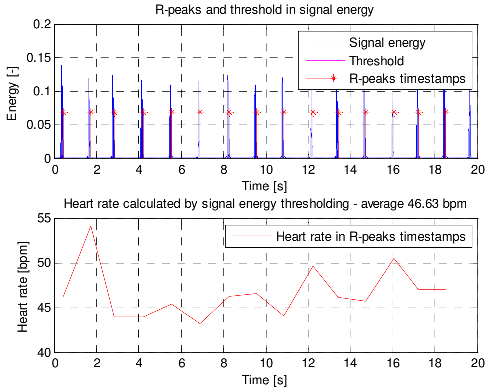

**Figure 7: R-peaks timestamps, threshold in signal energy and calculated heart rate frequency.**

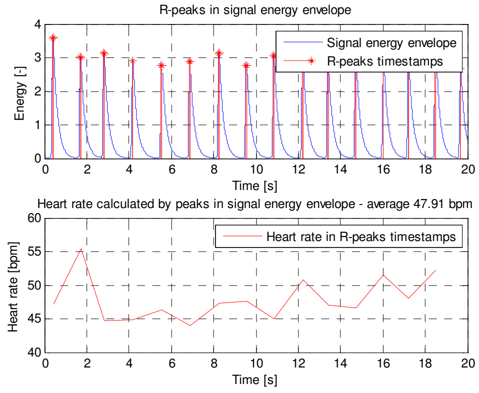

**Figure 8: R-peaks timestamps in signal energy envelope and calculated heart rate frequency.**

# 5. ALGORITHM COMPARISON

The quality of the designed algorithms was evaluated on ECG signals which were measured during physical activities, for example during pedaling on an exercise bike (Fig. 9) and exercising with dumbbells (Fig. 10).

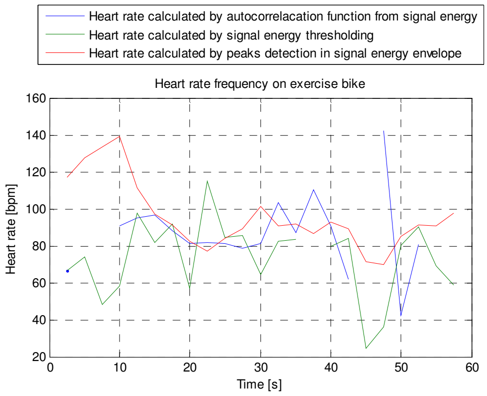

**Figure 9: Heart rate frequencies calculated with all three algorithms during pedaling on exercise bike.**

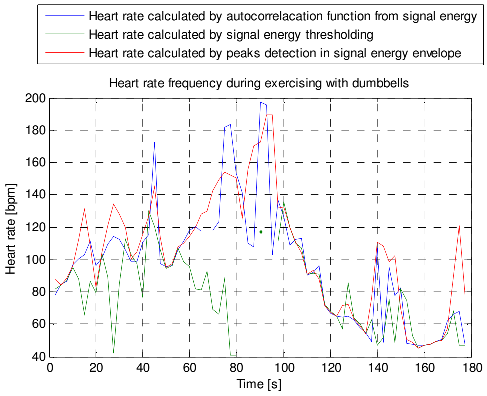

**Figure 10: Heart rate frequencies calculated with all three algorithms during exercising with dumbbells.**

The heart rate frequency was computed from the ECG signal in 4 s frames with a 2 s overlap. From these three algorithms, the most reliable and universal was the one which computes heart rate from peaks in signal energy envelope. This algorithm has not any missing parts or abnormal fast changes (Fig. 9, 10).

## 6. SOFTWARE IMPLEMENTATION

Designed digital filters and the algorithm for heart rate frequency calculation were implemented in ANSI C language and uploaded into the microprocessor in the development kit. The processor frequency was set on 72 MHz

The ECG signal sampling is a separate process in the program. The signal is sampled by frequency of fs = 500 Hz. The samples are automatically transferred from converter to memory using the direct memory access channel. Two buffers of 2 s signal length are created in memory.

The acceleration is measured by a 3D (XYZ axis) accelerometer in the development kit. The sampling frequency is 10 Hz. The result acceleration is calculated by equation (3).

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{3}$$

The heart rate is calculated every 2 s (fs = 0.5 Hz). Frames with length 4 s are used for heart rate calculation. The frames are 2 s overlapped. It means each 4 s frame contains 2 s of signal from the preceding frame.

Immediate heart rate is displayed on an LCD display and also is stored on a micro SD card with the information about immediate acceleration.

## 7. EXPERIMENTAL MEASUREMENT

Experimental measurements on several persons who performed various physical activities were made using the device. The records from test measurements are shown in Figure 11. Signals were recorded when the person was walking downstairs and upstairs from and to the 5th floor. The test subject had to repeat this activity twice. The person made 30s pauses in the basement and in the 5th floor. During the experiment, a timer was used for determining checkpoints. On the graph shown, the increasing heart activity caused by upstairs walking can be observed. The acceleration record provides information about the state of the tested person. The periods of walking upstairs or downstairs or the period of staying in the same place can be determined from the signal. This physical stress activity shows the dependence between heart rate frequency and acceleration very well. For the evaluation of results, are checkpoints from stopwatch in the graph are marked.

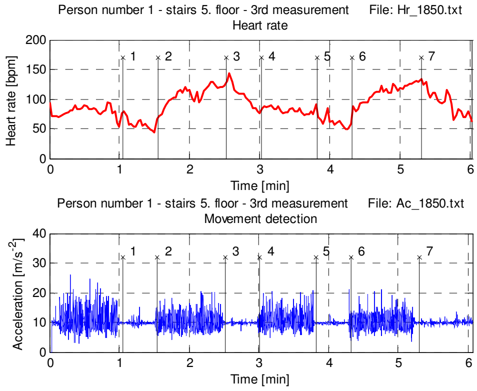

**Figure 11: Raw signals during walking upstairs and downstairs recorded on STM32-Primer2.**

The next experimental measurement was made with a person running and walking in a park. During the measurement, the record from professional heart rate monitor Polar F7 was obtained manually. The record was done roughly every 2.5 minutes, because the device does not allow data recording during measurement. On the graphs (Fig. 12) created from the recorded data with the said devices, the state of the person – i.e. whether (s)he runs, walks or idly stands – can be observed.

For the better comparing the data from development kit were filtrated by moving average filters. After this filtering, (Fig. 13) it is easy to see similarity between the curves from manual record by professional heart rate meter and the curves from automatic detection of hearth rate. On the other hand moving average filters remove the information about idly standing from the signal, but better reflect information about running and walking

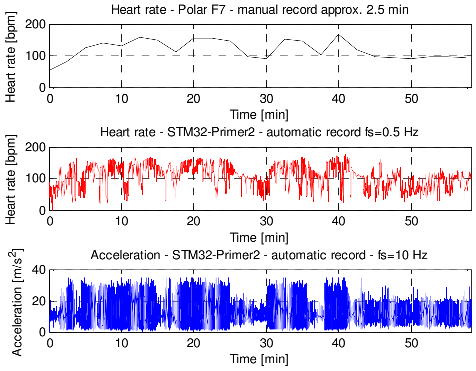

**Figure 12: Raw signals recorded on Polar F7 and STM32-Primer2 during running, walking and idly standing in a park.**

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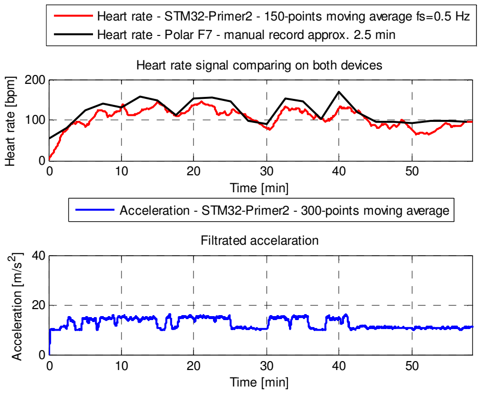

**Figure 13: Filtrated signals recorded on STM32-Primer2 and raw signal from Polar F7 during running, walking and idly standing in a park.**

# 8. CONCLUSION

Based on the experimental measurements it may be argued that created device obtains good records with information about heart rate and acceleration of sensed person. It can be used for heart rate monitoring during stress tasks and situation solving (biofeedback). In consideration of its small size it is suitable for example for heart rate monitoring and acceleration recording during hiking or climbing.

# 9. ACKNOWLEDGMENTS

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# 10. REFERENCES

[1] Friedrich, D., Aubert, X. L., Führ, H. and Brauers, A. 2004. Heart Rate Estimation on a Beat-to-Beat Basis via Ballistocardiography – A hybrid Approach. In *Proceedings of the 32nd Annual International Conference of the IEEE* EMBS (Buenos Aires, Argentina, August 31 – Sep. 4 2004). DOI= http://dx.doi.org/10.1109/IEMBS.2010.5627626.

[2] Steffen M., Leonhardt S. 2008. Non-Contact Monitoring of Heart and Lung Activity by Magnetic Induction Measurement. *Acta Polytechnica*, 48, 3/2008, 71–78.

[3] Sprager, S., Donlagic, D., Zazula, D. 2010. Monitoring of basic human vital functions using optical interferometer. In *Proceedings on the 10th International Conference on Signal Processing IEEE* (Beijing, China, October 24 - 28, 2010).DOI=http://dx.doi.org/10.1109/ICOSP.2010.5656473.

[4] Tenedero, M. C., Raya, D. A. M.., Sison, G. L. 2010. Design and implementation of a single-channel ecg amplifier with dsp post-processing in matlab. (Philippines, Nov 2010).

[5] Hartmann E., Company-Bosh E. 2003. ECG Front-End Design is simplified with MicroConverter. *Analog Dialogue.* 37 (November 2003).

[6] Danek, J. 2010. *CARDIOLOGY, ECG – basic information*. BTL zdravotnická technika, a.s., Prague, (March 2010).

[7] Kohler, B.U., Hennig, C., Orglmeister, R. 2002. *The principles of software QRS detection*. 21, 1 (Jan – February 2002), 42 – 57. DOI= http://dx.doi.org/10.1109/51.993193.

[8] Jacobson, A.L. 2001. Auto-threshold peak detection in physiological signals. In *Proceedings of the 23rd Annual International Conference of the IEEE* (October 25 – 28, 2001).DOI=http://dx.doi.org/10.1109/IEMBS.2001.1017206

[9] Nygårds, M., Sörnmo, L. 1983. Delineation of the QRS complex using the envelope of the e.c.g. *Medical and Biological Engineering and Computing*. 21, 5 (Sep. 1983), 538-547. DOI= http://dx.doi.org/10.1007/BF02442378.

[10] Billauer, E. 2008. *peakdet: Peak detection using MATLAB.* http://www.billauer.co.il/peakdet.html. (2008, September).