

# USING SIMULINK AND MATLAB FOR REAL-TIME ECG SIGNAL PROCESSING

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## Abstract

The paper describes a model for processing ECG signal for analyzing respiratory sinus arrhythmia (RSA) and heart rate variability (HRV). We implemented the model in Simulink and Matlab. Model had to work as real-time application for biofeedback purposes.

The measurement card HUMUSOFT AD512 measures ECG signal using xPC Target Library. Processing of ECG signal in Simulink results in heart rate (HR) signal. Simulink detects QRS complex in ECG signal and computes HR, which carries the information about HRV and RSA. The analysis of HRV calculates parameters in time and frequency domain. Simulink sends HR signal to Matlab, which determines and plots bars with relative spectral components, number of breaths in minute, period of breathing. Plots also include HR signal and its FFT transform and respiration pacer.

## 1. Measurement card HUMUSOFT AD512 and xPC Target

The measurement card HUMUSOFT AD512 [1] measured ECG signal with sampling frequency of 1kHz. The card disposes of 12 – bit analog-digital converter and needs ISA bus, which was inserted in an old computer. In Simulink, HUMUSOFT AD512 supports libraries: Real-Time Windows Target, Extended Real –Time Toolbox a xPC Target [4][5]. We decided to employ xPC target library because of instability of hardware when using Real – Time Windows Target library. xPC Target library divides tasks between two computers – Target PC and Host PC. Target PC runs real-time programs on its own operating system. Host PC is used for designing and developing models. PCs communicate via serial bus or internet protocol.

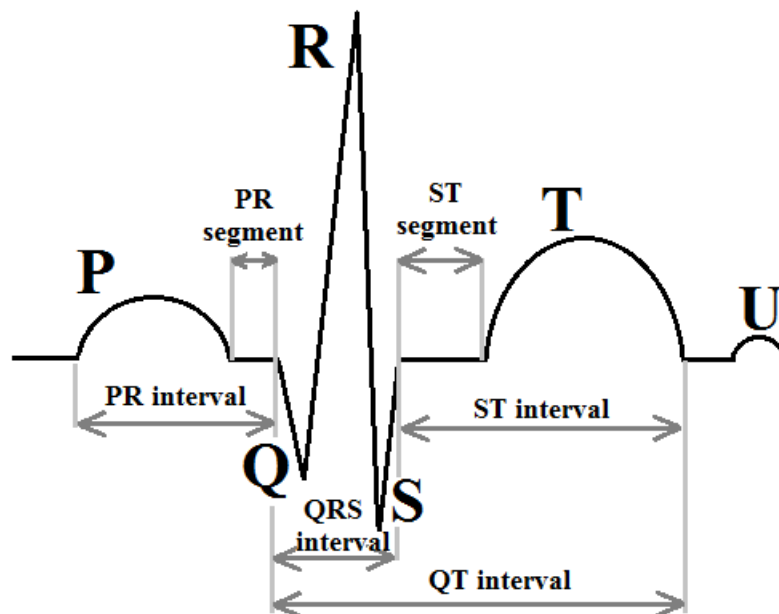


Figure 1: Typical ECG signal with specified waves, intervals and segments

## 2. The model in Simulink

Figure 1 shows a typical ECG pattern. QRS complex detection is fundamental for computing HR [8]. R – wave is positive waveform in QRS complex. RR – interval characterizes time between two successive R – waves. HR (beats/min) is calculated by (1)

$$HR = \frac{60}{RR - interval} \quad (1)$$

Processing in Simulink results in HR signal. Figure 2 shows model made in Simulink. It consists of four subsystems: *AD512*, *Filtration*, *RR detector*, *Time MEAS HR*

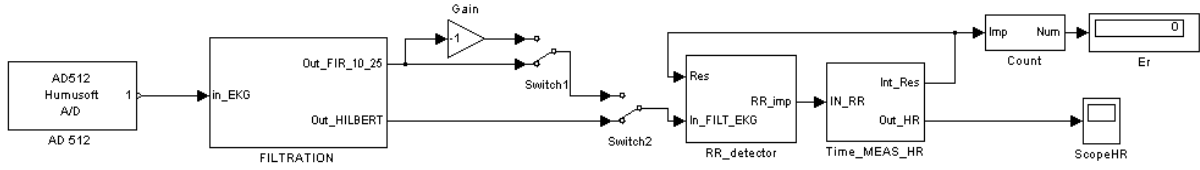


Figure 2: Simulink model processes ECG and output is HR signal

Subsystem *AD512* represents measurement card, which brings ECG signal to the model. The sampling frequency was set to 1 kHz. Filtration subsystem disposes with two selectable filters: Band-pass FIR filter with cutoff frequencies 10 Hz and 25 Hz and order of 178, Hilbert transform combined with band-pass filter. Hilbert transform of real signal  $x(t)$  is defined:

$$x_H(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{t - \tau} d\tau = x(t) * \frac{1}{\pi t} \quad (2)$$

In frequency domain Hilbert transform is calculated:

$$X_H(j\omega) = X(j\omega) \cdot [-j \cdot \text{sgn}(\omega)] = X(j\omega) \cdot H(j\omega) \quad (3)$$

where transfer function of Hilbert transform  $H(j\omega)$  is defined:

$$H(j\omega) = \begin{cases} -j & 0 \leq \omega \\ j & \omega > 0 \end{cases} \quad (4)$$

Hilbert transformer transfer function of discrete signal  $H(e^{j\theta})$  is defined:

$$H(e^{j\theta}) = \begin{cases} -j & 0 \leq \theta < \pi \\ j & -\pi \leq \theta < 0 \end{cases} \quad (5)$$

Hilbert transform  $x_H(n)$  is used for calculating the envelope  $x_e(n)$  of ECG signal  $x(n)$ .

$$x_e(n) = \sqrt{x^2(n) + x_H^2(n)} \quad (6)$$

Using an approximation of the envelope  $x_e(n)$  is computationally preferable:

$$x_e(n) \approx |x(n)| + |x_H(n)| \quad (7)$$

Figure 3 shows output of Hilbert transform combined with band-pass filter. Subsequently, model calculates the envelope of analytic signal. Output in form of positive waves is appropriate for

QRS detection. We used frequency asymmetric band-pass FIR filter to get analytical signal. Impulse response of asymmetric band-pass FIR filter is calculated by frequency shifting of low-pass filter. Shifting was computed in time domain by multiplication with complex exponential. We realized filter in Simulink, which processes two branches: one with real part of the signal, second with imaginary part of the signal.

Hilbert transform solves problem of ECG signal polarity, which may be caused by wrong electrode placement [7].

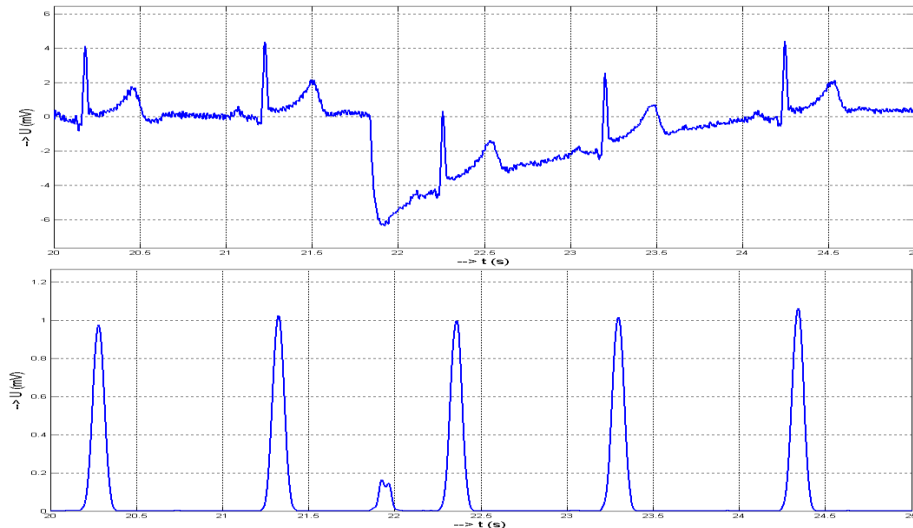


Figure 3: ECG signal and output of Hilbert transform combined with band-pass filter

Subsystem *RR detector* (Fig. 4) detects QRS complex. Important blocks are Compare to constant (set to 0.5) and Detect increase. QRS complex occurs when amplitude of signal is higher than constant and when signal stops increasing. AND operator evaluates logical values from Compare to constant and Detect increase [2]. Output of AND operator and subsystem *RR detector* are impulses in time of QRS complex.

Subsystem *Time Meas HR* (Fig. 5) measures the time between two R – waves called RR interval and calculates HR from (1). Integrator provides the measuring of RR interval by integrating constant set to 1. Impulses from *RR detector* reset Sample and Hold block which holds the value of RR interval. Math function and Gain together compute HR. Subsequently, Simulink sends HR signal to Matlab for processing.

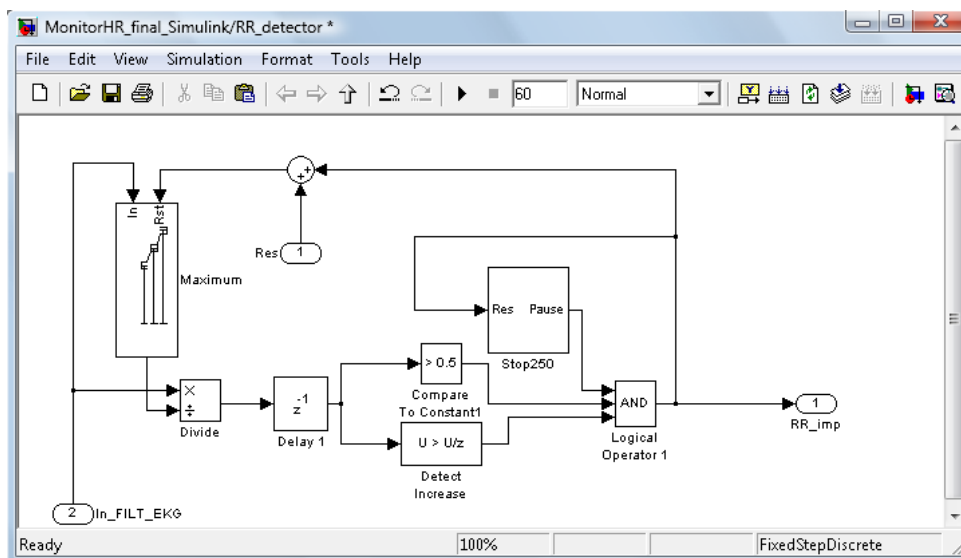


Figure 4: Blocks of subsystem RR detector detect R - waves

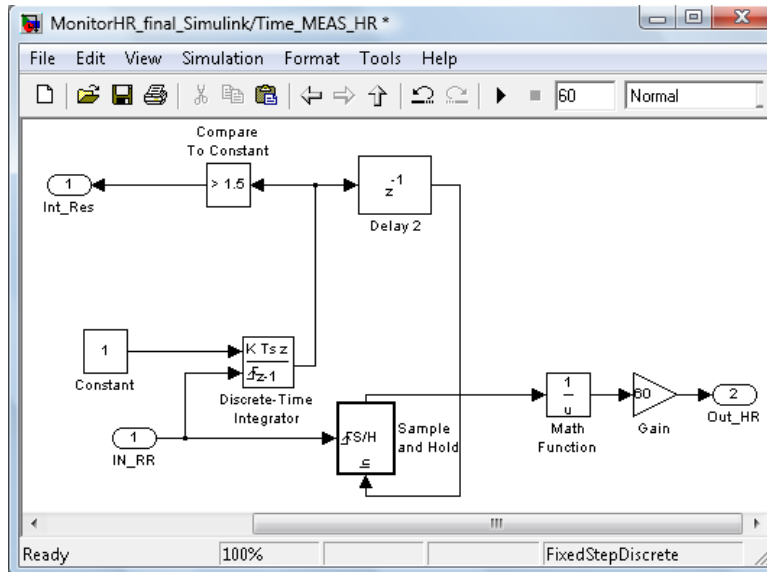


Figure 5: Blocks of subsystem Time MEAS HR compute HR

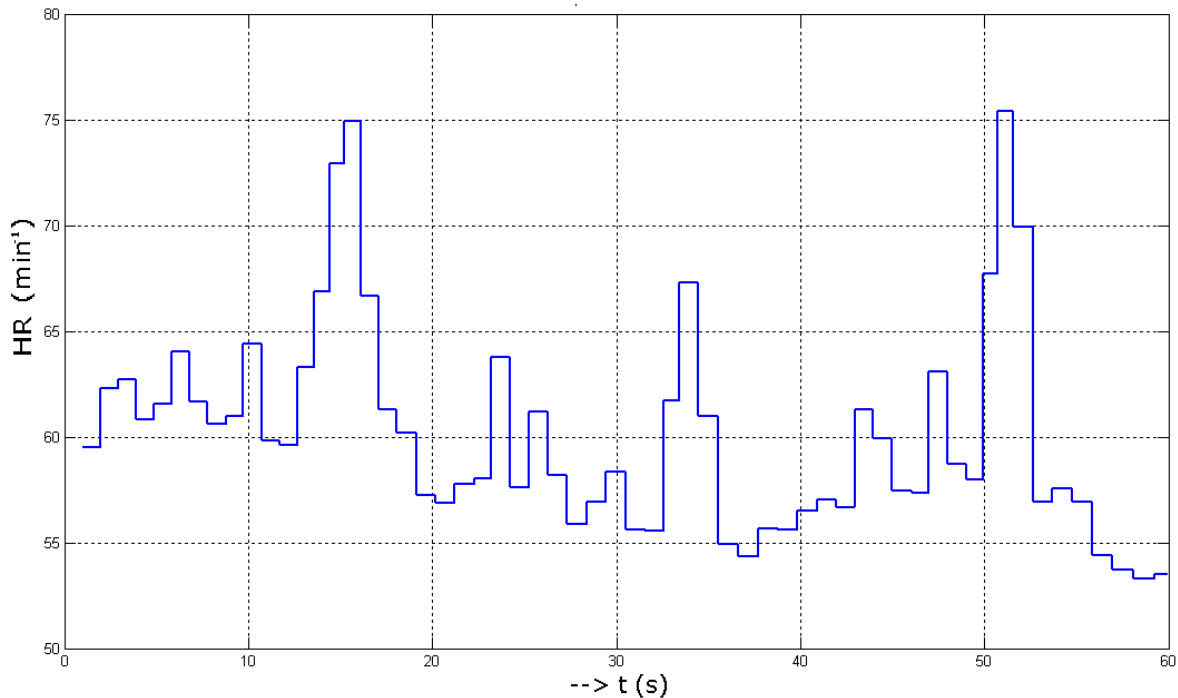


Figure 6: HR signal

### 3. Processing in Matlab

Matlab is used for processing HR signal. We designed GUI for that purpose, where function “timer” is called. This function ensure calling any function in precise frequency. In fact, “timer” frequency defines sampling frequency in which Matlab takes samples from HR signal. Sampling frequency of HR signal is set to 10 Hz. Figure 7 shows GUI at work. Control is provided by menu. Main parts of GUI are two axes. First axis represents 30 sec. of HR signal, second axis displays FFT transform of HR signal. User can choose between two window function – Hamming and Hann. FFT spectrum is important for calculating parameters of HRV analysis. These parameters include total spectral power in defined frequency region.

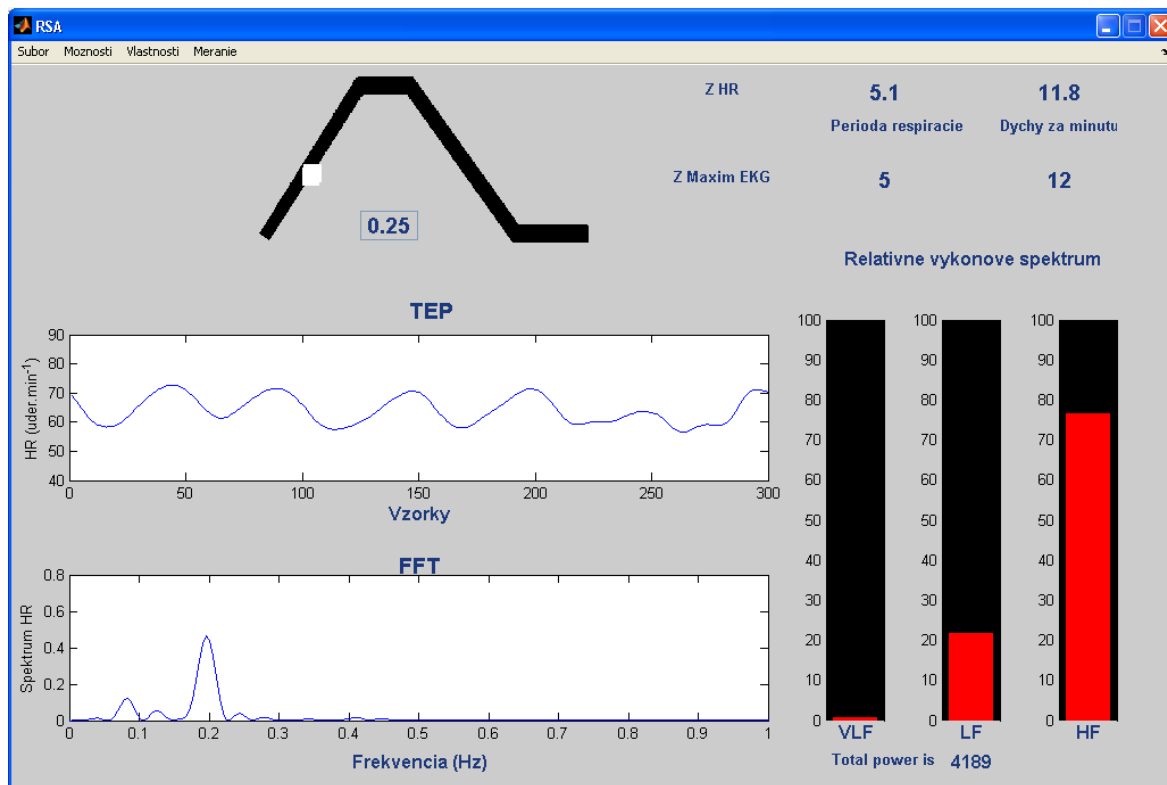


Figure 7: Matlab GUI at work

HRV analysis divides frequency spectrum into [3][9]:

- VLF – very low frequency – between 0.003 Hz and 0.04 Hz
- LF – low frequency – between 0.04 Hz and 0.15 Hz
- HF – high frequency – between 0.15 Hz and 0.4 Hz

Bar plots (at the bottom on the left) represent relative spectrum in VLF, LF and HF region. Breathing activity is (usually) reflected in HF region. Breathing activity parameters (at the top on the left) contain respiration period and number of breaths in one minute [6]. GUI also includes respiration pacer, which is used in paced breathing. Line going up represents inhalation and line going down represent exhalation. White dot is moving on the respiration pacer to show current breathing process.

RSA influences HRV. RSA is rhythmic fluctuation in heart rate (RR – interval) at respiration frequency. Using FFT analysis applied on heart rate signal helps to find respiration frequency (in Fig. 7, respiration frequency is 0.2 Hz). Finding respiration frequency is the key for computing respiration period and number of breaths in one minute.

## 4. Results

Developed program in Matlab can perform HRV biofeedback training. One method of biofeedback involves slowing the breathing rate to resonant frequency. At resonant frequency, amplitude of HRV is maximized. Other method consists of switching respiration pacer on and off. Aim is to keep the same breathing frequency when the respiration pacer is off.

We realized trial measurement with functional generator capable of setting synthesized ECG signal as output. Wobbling of frequency of ECG provided simulation of RSA. Other measurement were realized on volunteers. Co-operation of Simulink with xPC target and Matlab proved to be applicable for analyzing HRV and RSA parameters in real time.

## References

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