ECG signal analysis,
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Iwona KOSTORZ[1], Włodzimierz KOWALSKI[1], Zbigniew LUDWIG[1], Jan ZAJĄC[1],
Adam PIASECKI[1],Michał SOCHA[1], Wojciech GÓRKA[1]

A PRELIMINARY STUDY OF THE UTILIZATION OF A LOW RESOLUTION ECG SIGNAL FROM HANDHELD ECG MONITOR

The paper presents the preliminary study of the utilization of a low resolution ECG signal analysis. The analysis was performed on the signals obtained from a hand-held ECG monitor usually used in primary health care.
The aim. The main aim of the study was a registration of series of data by volunteers within couple of months and determination of signal quality and main ECG parameters as follows: Q, R, S waves, QRS duration as well as the end of PQ and the beginning of ST segment. Additionally, the heart rate variability was determined.
Materials and methods. The data was registered by 12 volunteers aged from 35 to 55. The ECG tests were carried out for 7 months. The sample rate of the signal was 100 Hz. To determine the ECG parameters the signal processing and statistical methods was used.
Results. The sensitivity of the following ECG parameters were: R wave detection - 99,2 %, Q wave detection - 99,1 %, S wave detection - 99,0 %, QRS duration - 99,2 % respectively.

1. INTRODUCTION

Secondary prevention of coronary heart disease include therapeutic interventions and actions to reduce the incidence of complications and relapses, as well as inhibiting the progression of lesions. It affects the following groups of patients: with stable coronary artery disease after acute coronary syndromes, post-operative revascularization (percutaneous coronary intervention) or surgical. An important element of this prevention is regular ECG test. These tests can be performed remotely (at patient's home) with a portable recorder, and collected test results must be interpreted by a medical specialist. An important component of such telemedical system collecting information from performed remotely multiple tests is a screening of the results (especially reporting on alarm states).
This work was a preliminary study focused on utilization of the low frequency signal that was derived from a hand-held certified ECG monitor usually used in primary health care. The main aim was an investigation whether the data obtained from such a monitor is useful for a telemedical system used in secondary prevention.

[1]Institute of Innovative Technologies EMAG, ul.Leopolda 31, Katowice, Poland

2. MATERIALS

The used system consisted of following components: hand-held ECG monitors for personal use, remote database collecting the test results and ECG analysis module. The conformance of the monitor to regulatory standards: safety: IEC 60601-2-47, electromagnetic compatibility: IEC 60601-1-2, performance standard: ANSI\AAMI EC38-2007.
The data was obtained with the use of five-lead Mason-Likar system presented in the Fig.1. Twelve volunteers participated in the test. Ten of them were not previously diagnosed with heart disease and two were after a cardiac incident. Before the tests, each person had been instructed on how to properly attach the monitor electrodes. During the test everyone was doing it by himself at home. Each test had to last minimum 2 minutes. The data was transmitted through the wireless connection to the main database and analysed. The data sampling rate was 100 Hz. The signal was pre-filtered with the bandpass filter 0.05-49.5 Hz.

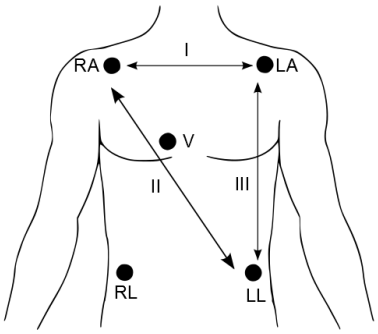

Fig. 1. Five-lead Mason-Likar system.

3. METHODS

The used methods were a compiled set of solutions focused on fast data analysis. There are lots of algorithms of ECG signal processing employing a variety of methods [3], [4], [5], [7], [9], [10], [11], [13]. The authors decided to use the simplest and not sophisticated as well as experimental methods for reaching the shortest time of analyses. The steps of ECG data processing is given in the following subsections.

3.1. OVERSMAPLING AND SIGNAL QUALITY

The signal was oversampled to 500 Hz according to recommendation AHA/ACC/HRS [2]. The oversampling method was based on FIR (Finite Infinite Response) low-pass filter. The original signal was up-sampled to the recommended sampling rate with 0 values and filtered with the FIR filter. The coefficients of the filter was calculated with the sinus cardinalis (sinc) formula (1). The oversampling results has been shown in the Fig. 2

$$sinc = \begin{cases} \frac{sinx}{x} & \text{if } x \neq 0 \\ 0 & \text{if } x = 0 \end{cases} \tag{1}$$

To prevent the analysis of noisy signals (primarily including myogenic artifacts) the signal to noise ratio (SNR) was calculated according to the formula (2). If SNR reached the threshold 25 dB the signal would be further analysed [3], [9].

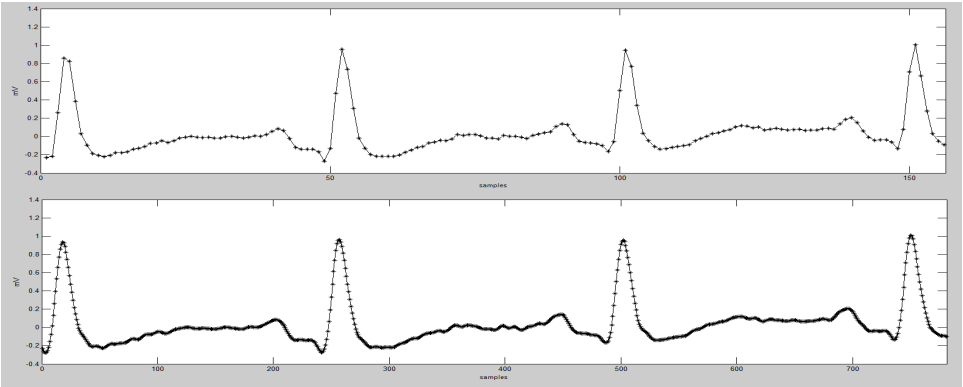

Fig. 2. Oversampling results.

$$SNR = 10 \log \frac{E_S}{E_N} \tag{2}$$

where:

- E_S is the energy of the signal without the noise,
- E_N is the energy of the noise.

3.2. ELIMINATION OF ISOELECTRIC LINE DRIFT

The next step was an elimination of the drift and determination of the isoelectric line. The drift was reduced by subtracting the low frequency noise from the signal. The signal was filtered with the low pass filter (0.6-1.2 Hz) and the result was treated as noise.
After the elimination process the isoelectric line was calculated as 2-quantile.

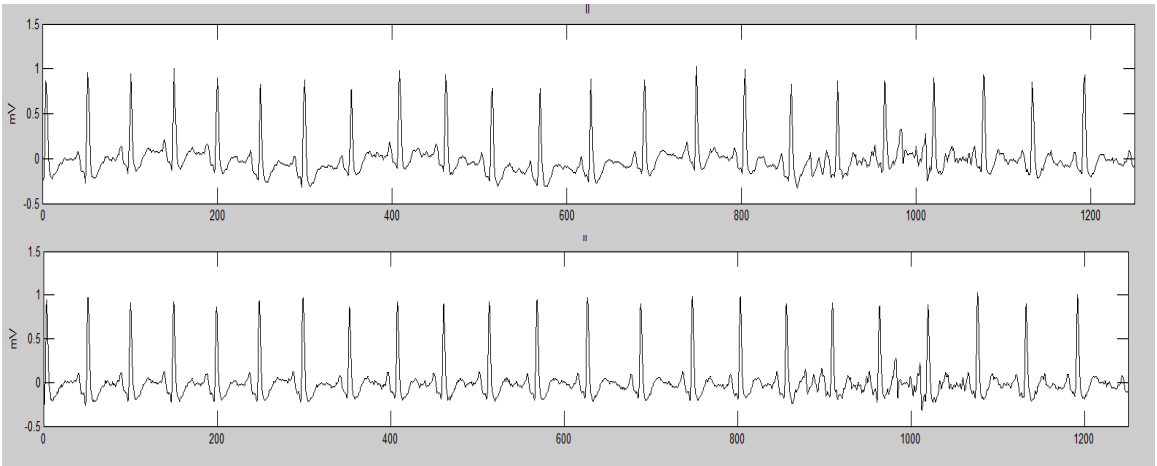

Fig. 3. Removing the isoelectric line drift.

3.3. QRS COMPLEX DETECTION

To determine the QRS complex position in the signal the R peak had to be detected. At first the signal was filtered with the bandpass filter (5-20 Hz) [15], [14]. Next, to detect R

peaks a describing function (DF) proposed by Frankiewicz et.al. was used [9]. The result of the function was averaged with the zero phase filter. The result of the operation is given in the Fig. 4. Each R peak was determined by a maximum of the DF function.

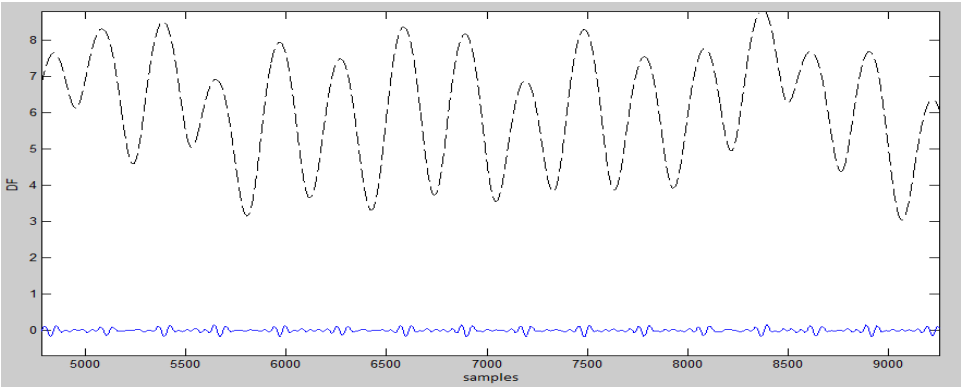

Fig. 4. The result of the descriptive function. DF function (upper curve), filtered signal (lower curve).

3.4. WAVES AND SEGMENTS DETECTION

The set of analysed ECG waves and segments was limited to Q, R, S waves as well as PQ and ST segment. To determine mentioned waves an averaged signal of cardiac cycles was used. Indexes of samples representing R peaks were established as reference points to create the averaged cardiac cycle.

3.4.1. DETECTION OF Q AND S WAVES

Basing on the definition of the Q wave that it is a first negative deflection to the left of the R peak ([6], [8], [12]) the wave must meet three criteria:

- the Q wave is a local minimum in the range of samples ($R_{peak} - 60$, R_{peak}) ms,
- this is a point for which the rate of decent of the left R wave slope is minimal,
- the value of the peak must lie under the isolectric line.

The S wave is a first negative deflection to the right of the R peak and it must meet following criteria:

- the S wave is a local minimum in the range of samples (R_{peak}, $R_{peak} + 60$) ms,
- this is a point for which the rate of decent of the right R slope is minimal,
- the value of the peak must lie under the isolectric line.

Changes of the R wave slope decent have been shown in th Fig. 5

3.4.2. DETECTION OF PQ AND ST SEGMENTS

PQ segment represents the atria repolarisation time. It starts with the end of the P wave and ends with the beginning of the QRS complex [6], [8], [12]. In a correct electrocardiogram it should go along with isoelectric line.
For determination of PQ segment three criteria was assumed:

- the PQ segment was expected to appear in 120 ms before the R wave did,
- changes of the signal velocity (according to the formula (3)) can not exceed the range of ± 0.002 mV - the value was determined empirically,

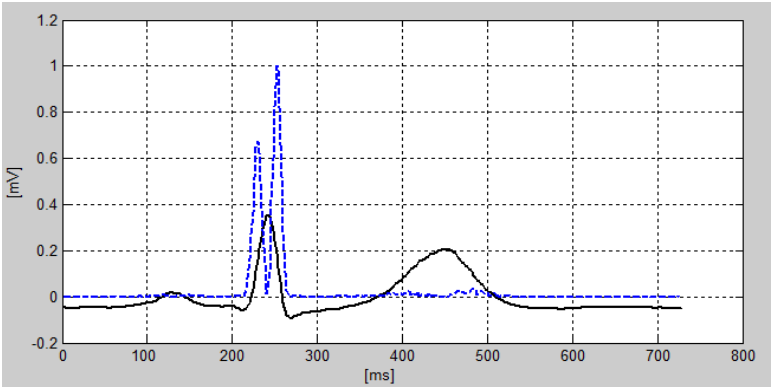

Fig. 5. Changes of the velocity chart (the dashed line).

- the time of the velocity changes in the specified range must last 40-100 ms.

The ST segment determination was performed similarly to the PQ segment with the difference that:

- the ST segment was expected to appear within 200*ms* after the R wave did,
- changes of the signal velocity can not exceed the range of ± 0.002 mV,
- the time of the velocity changes in the specified range should last 80-120 ms,
- the acceleration changes according to the formula (4) should not exceed ± 0.03mV

$$Vel(i) = \frac{x_{i+1} - x_i}{t_s} \tag{3}$$

$$Accel(i) = \frac{x_{i+1} - x_i}{t_s^2} \tag{4}$$

where:

- i - is the index of a sample, $i = 1..N$,
- t_s - is a time between two adjacent samples.

The last criterion is not met for particular ECG records of young people. In this case the ST segment is not a line but a looks like a fragment of parabola. Therefore as the beginning of the ST segment is accepted a first sample meeting criteria 1 and 2 and for which the value of acceleration has the minimal value.

3.5. QRS DURATION

The approximate QRS complex duration corresponds to the time from the beginning of the Q wave to the end of the S wave. These points are the end of the PQ segment and the beginning of the ST segment. The QRS complex duration was calculated with the formula 5.

$$QRS = \frac{ST_1 - PQ_n}{t_s} \tag{5}$$

where:

- ST_1 - is the first sample of the ST segment,
- PQ_n - is the last sample of the PQ segment.

3.6. HEART RATE VARIABILITY

Finally, the average value of the heart rate was calculated with the formula below and changes of heart rate variability presented in the Fig. 6.

$$HR = \frac{60 * f_s'}{RR} \tag{6}$$

where:
- f_s' – sampling frequency (oversampled),
- RR - mean value of the time between two adjacent R peaks.

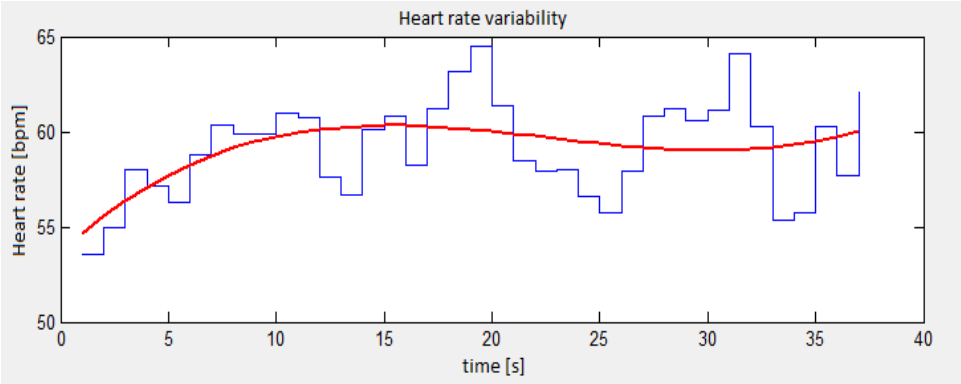

Fig. 6. The heart rate variability.

4. SUMMARY AND CONCLUSIONS

The presented algorithm was verified on signals obtained from 12 people aged from 35 to 55. The ECG tests were carried out by volunteers themselves in the period of 7 months. It was impossible to make test if at least one of ECG monitor electrodes had a poor contact or it would be detached.
Several assessment criteria of the effectiveness of the algorithm had been established:

- sensitivity of R Wave detection,
- sensitivity of Q Wave detection,
- sensitivity of S Wave detection,
- sensitivity of QRS duration.

Two additional criteria also was set:

- sensitivity of test duration,
- sensitivity of noise detection,

The sensitivity of the solution was calculated in two ways marked as (a) and (b) respectively. To check how many registered data files were analysed correctly following conditions were established (a):

- it was assumed that all R, S and Q waves that can be well distinguish by an expert must be found in the ECG signal,
- if a peak was detected in the other point of the signal then it should be the analysis was qualified as incorrect,
- if a specific peak was omitted the analysis was qualified as incorrect as well.

In the second way (b) the sensitivity was given according to its definition: $sensitivity = \frac{NumberOfWavesDetected}{TotalNumberOfWaves}$

Table 1. Sensitivity of the algorithm with respect to the (a) and (b) conditions.

Criteria	Sensitivity (a)	Sensitivity (b)
R Wave detection	96,6%	99,2%
Q Wave detection	95,5 %	99,1%
S Wave detection	94,3 %	99,0%
QRS duration	96,6 %	99,2%
Test duration	100,0%	100,0 %
Noise detection	100,0%	100,0%

The absolute error of Q and S peaks detection does not exceed 3 samples (after oversampling process). Correct QRS duration values have been calculated in spite of inaccurate Q and S peaks detection due to the fact the QRS complex extends from the beginning of the Q wave to the end of the S wave (not peaks). These points have been determined as the end of the PQ segment and as the beginning of the ST segment respectively [3], [6], [8]. Determination and analysis of the PQ ans ST segments was not the aim of this work. Authors attempted to determine them only for finding the QRS complexes duration. The relative error of analysed ECG parameters determination does not exceed 0.9%.

Most of the QRS detection algorithms operate on high resolution ECG signals. Authors usually verify efficiency and accuracy of the algorithms using data registered by Holter method or MIT-BIH database [1]. There was not found a research on analysis EGC signals derived from hend-held ECG devices for personal use (without the participation of qualified staff) to compare with. Comparing the results to high resolution ECG signal analyses the preliminary results allow to conclude that registered data after the oversampling process is useful for basic ECG parameters analysis. The results of preliminary study are considered to be encouraging and promising. Number of hend-held ECG monitors is still growing. They are relatively cheap and seems to be a good equipment for distributed telemedical systems used in secondary prevention.

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