RECOMMENDATIONS FOR ECG ACQUISITION USING BITALINO

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Abstract: Cardiovascular disorders are still the most common cause of death in Western countries. In addition to cardiologists´ care, patient self-examination is the growing area nowadays. For this purpose, mobile devices for ECG signal acquisition are suitable. From these devices, we selected low-cost system called BITalino. In this work, we tested the quality of ECG signals acquired with BITalino under various conditions. We tested 2 values of sampling frequency, 12 electrodes placements and 6 types of exercises. We recommend using sampling frequency of 1,000 Hz, two electrodes placements – on chest and on wrists for both resting and exercise ECG.

Keywords: BITalino, ECG, electrocardiogram, acquisition, sampling frequency

1. INTRODUCTION

The areas of telemedicine and especially patient self-examination using mobile applications are developing very fast nowadays. For this purpose, mobile and ideally wireless devices are necessary for acquiring physiological data. The data are wirelessly sent to access point (smartphone, tablet, PC), special application process them and the user is informed about their health condition. Another possibility is that the data can be sent from access point to database via the Internet and doctors evaluate them. In our work, we deal with the first part of this process, which is common for both approaches – data acquisition. We focus on electrocardiogram (ECG) signal only.

There are several commercial systems for ECG signal acquisition (e.g. [1], [2] and [3]). For our purpose (developing mobile application for wide spectrum of users), we need accessible, low-cost, open (we need the signal in a standard file format, such as *.txt*) and accurate system. The acquisition accuracy is important because in our future work we will evaluate pulse, heart rate variability and the most common heart pathologies (premature atrial or ventricular contractions, atrial fibrillations, sinoatrial blocks, atrioventricular blocks and left and right bundle branch blocks). BITalino acquisition system fulfills these conditions that is why we use it for ECG signal acquisition. Moreover, the system is small, user-friendly, and on the Internet there are available APIs (Application Programming Interfaces) for different platforms for free. [3]

In this work, we tested the quality of ECG signals acquired with BITalino under various conditions, namely sampling frequency, electrodes placements and quality of recorded signals. BITalino is described in chapter 2.1. The conditions are mentioned in chapters 2.2, 2.3 and 2.4. Chapter 3 deals with results. In the end, we recommend proper conditions for a good quality ECG acquisition.

2. METHODS

2.1. BITALINO ACQUISITION SYSTEM

BITalino is a multimodal system for biomedical data acquisition. It consists of microcontroller unit, Bluetooth (BT) module for wireless communication and power block with a Lithium Ion Polymer battery (Figure 1). In one board, 6 various measurement sensors for bioelectrical and biomechanical data acquisition are integrated (Figure 1). BITalino enables acquisition of electrocardiogram, electromyogram (EMG), electrodermal activity (EDA) and accelerometry (ACC). Light sensor (LUX) and Light-Emitting Diode (LED) are included as well. Light sensor enables ambient light monitoring. Both Light sensor and LED enable synchronization with third party equipment. [4], [5], [6]

ECG signal acquisition with BITalino is noninvasive; ECG is sensed by three Ag-AgCl electrodes. BITalino enables one lead measurement with sampling frequency (f_s) of 10/100/1,000 Hz. The bandwidth is 0.5-40 Hz, in this range the accuracy is guaranteed. The system transfers frequencies from 40 Hz to the half of the sampling frequency as well, but with smaller magnitude. The resolution of ECG signal is 10 bits. The acquired voltage range is limited to (-1.5, +1.5) mV. Data can be visualized by the software OpenSignals, which enables real-time data acquisition and offline browsing. Recorded data can be stored in a standard ASCII file format (.*txt*) or in the HDF5 format. [4], [5], [6]

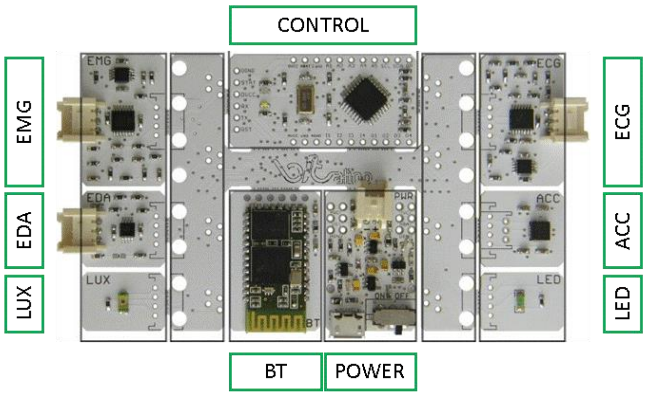

Figure 1: BITalino board consists of microcontroller unit (CONTROL), Bluetooth module (BT), power block (POWER) and 6 sensors for various data acquisition. [5]

2.2. Sampling frequency

BITalino generally enables to set 3 values of sampling frequency (10 Hz, 100 Hz and 1,000 Hz). For ECG acquisition, only 100 Hz and 1,000 Hz are considered. We tested both of these frequencies in terms of preserving the diagnostic information.

2.3. Electrodes placements

We tested 12 electrodes placements in terms of signal quality and patient comfort. The exact location of each electrode is given in Table 1. The best electrodes placement(s) will be determined as a compromise between signal quality (amount of diagnostic information) and patient comfort. Hands are more accessible and comfortable body parts for electrodes placement than chest. On the other hand, we expected that the signal from hands has lower quality and magnitude than the signal sensed from chest.

The electrodes placements were determined with respect to standard ECG leads, body part accessibility, assumed amplitudes and design of BITalino. The lead set is 30 cm long, which means that the distance between two electrodes (body parts) should be no more than 60 cm. From standard ECG leads, we take into consideration only limb leads (because they are bipolar). Moreover, the distance between hand and leg is greater than 60 cm, so the sensing is very uncomfortable. The only standard lead, which can be used is limb lead I (left hand, right hand).

The signals were acquired for 1 minute with f_s = 1,000 Hz. The patient was sitting on chair with hands laid on thighs.

All the tests in this paper were performed on three healthy subjects.

No.	Plus	Minus	Reference
1	center of right palm	center of left palm	upper part of right palm
2	under right clavicula	under left musculus pectoralis major	under left clavicula
3	right wrist	left wrist	right wrist closer to pinky
4	right wrist	left wrist	right wrist closer to thumb
5	right wrist	left wrist	left wrist closer to pinky
6	right wrist	left wrist	left wrist closer to thumb
7	sternum	under left pectoral muscles	under sternum
8	sternum	serratus anterior	under sternum
9	sternum	latissimus dorzi	under sternum
10	sternum	under left pectoral muscles	serratus anterior
11	sternum	latissimus dorzi	serratus anterior
12	right thumb	left thumb	right wrist closer to pinky

Table 1: 12 tested electrodes placements.

2.4. EXERCISE ECG

We tested the signal quality while the patient was moving (exercise ECG). We tried a few types of movements, because they can influence the signal in a different way. It depends especially on electrodes placement. Based on chapters 2.2 and 2.3 and results 3.1 and 3.2, we set the sampling frequency on 1,000 Hz and choose two proper electrodes placements (No.2 – chest and No.6 – hands).

The subject was doing each exercise for one minute, than they had 10 seconds to get ready for the next exercise. The acquisition was continual for one electrodes placement and all the exercises (total 6 minutes and 50 seconds). BITalino was hanged on the neck.

To quantify quality of the signal, we used segmentation algorithm [7] based on SNR estimation. The algorithm segmented signal into 3 quality groups. The 1st group – "low noise" (1) has very low level of noise, which means that the signals can be delineated. In the 2nd group – "medium noise" (2), level of noise is higher but still enables to use the signal for QRS detection. The 3rd group – "high noise" (3) includes signals with small SNR; they are not appropriate for further processing.

3. RESULTS

3.1. TESTING OF SAMPLING FREQUENCY

The acquired signals were compared visually by two experts in terms of details. In case of f_s = 1,000 Hz, more details are preserved, but the signal is 10× longer. In case of f_s = 100 Hz the signal is smoother, but some details are lost (rapid changes). These details are important for diagnosing some pathologies (e.g. bundle branch blocks). The sampling frequency should be set with respect to required diagnostic information. F_s = 100 Hz is enough for rhythm monitoring. For morphology assessment, f_s = 1,000 Hz is necessary.

3.2. TESTING OF ELECTRODES PLACEMENTS

After signals acquisition, we evaluated them manually (results are shown in Table 2) in terms of:

- presence of three important components (P, R, T) – 0 means absence, 1 means presence and the component is quite small, 2 means presence and the component is significant (every component in each cycle always belongs in one group (0, 1, 2) within one signal),
- trimming of R wave – Y (yes)/N (no),
- amplitudes of R and T,
- noise - 0 absence, 1 very low level, 2 low level, 3 high level (different scale than in the segmentation algorithm [7]),
- isoline – shift of isoline, drift (D).

Electrodes Placement	Presence of components									Trimming of R wave			Amplitude [mV]						Noise			Isoline [mV]		
No.	P			R			T						R			T								
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
1	1	0	2	2	2	2	2	2	2	N	N	N	0.7	1.4	0.25	0.2	0.4	0.1	1	1	1	0	-0.05	-0.05
2	2	2	2	2	2	2	2	2	2	Y	N	N	> 1.5	1.5	1	0.4	1	0.3	0	0	1	-0.05	-0.1	-0.1
3	1	0	2	2	2	2	2	2	2	N	N	N	0.7	1.4	0.3	0.3	0.4	0.1	1	1	1	0	-0.05	-0.05
4	1	0	2	2	2	2	2	2	2	N	N	N	0.7	1.4	0.3	0.2	0.4	0.1	1	1	1	-0.05	-0.05	0
5	2	0	2	2	2	2	2	2	2	N	N	N	0.7	1.4	0.3	0.2	0.4	0.1	1	1	1	0	-0.05	0
6	1	1	2	2	2	2	2	2	2	N	N	N	0.6	1.4	0.3	0.2	0.4	0.1	2	1	1	-0.05	-0.05	0+D
7	2	1	2	2	2	2	1	1	2	Y	Y	Y	> 1.5	> 1.5	> 1.5	0.1	0.3	0.2	1	1	0	0	0	0+D
8	2	2	1	2	2	2	1	0	1	Y	Y	Y	> 1.5	> 1.5	> 1.5	0.1	0.1	0.1	1	1	1	0	0	0
9	2	1	1	2	2	2	1	2	1	Y	Y	Y	> 1.5	> 1.5	> 1.5	0.1	0	0.1	1	1	2	0	-0.05	0+D
10	2	2	1	2	2	2	2	2	1	Y	Y	Y	> 1.5	> 1.5	> 1.5	0.1	0.3	0.1	0	1	1	0	0	0+D
11	2	1	1	2	2	2	1	1	0	N	Y	Y	1.4	> 1.5	> 1.5	0	0	0	1	1	2	0	0	0
12	2	0	1	2	2	2	2	2	2	N	N	N	0.7	1.3	0.25	0.25	0.4	0.1	1	2	1	-0.05	0	0

Table 2: Quality of the signals sensed with different electrodes placements.

According to the results in Table 2, it was determined that the best signals were achieved with electrodes placement No.2 and No.6. In case of electrodes placement No.2, positive electrode is placed under the right clavicula, negative electrode under the left musculus pectoralis major and reference electrode under the left clavicula. In case of electrodes placement No.6, positive electrode is placed on the right wrist, negative electrode on the left wrist and reference electrode is placed on the left wrist closer to the thumb. The signals sensed with the two electrodes placements show significant presence of all components (P, Q, R, S, T). The R wave was trimmed in one subject in signal sensed with electrodes placement No.2. The trim was more significant while sensing from other places on chest (electrodes placement No.7-10). In case of electrodes placement No.2, components have higher amplitudes (mean value: 1.3 mV for R wave and 0.7 mV for T wave) than in case of electrodes placement No.6 (mean value: 0.75 mV for R wave, 0.23 mV for T wave). In both cases, the signals have very low or low level of noise. Shift of isoline is not significant.

The amplitude of signal components varies from subject to subject. It depends especially on subject´s constitution, skin impedance and physical condition. BITalino has limited voltage range (-1.5, +1.5) mV, that is why the signal with higher amplitude is trimmed. For further analysis is appropriate to use signal which is not trimmed. These are the reasons, why we determine two electrodes placements. For subjects with higher amplitudes of ECG signal, we recommend electrodes placement No.6. For subjects with smaller amplitudes, we recommend electrodes placement No.2.

3.3. TESTING THE QUALITY OF EXERCISE ECG

Table 3 shows the signal quality during exercise ECG acquisition. Presence of noise was evaluated using the method proposed in [7] and briefly described in chapter 2.4 of this paper. The algorithm classified each whole signal into one group (it means the signal has constant level of noise). The algorithm evaluated all signals sensed from chest as "low noise" (signal quality 1). Signal quality was determined as "low noise" or "medium noise" (1 or 2) in the case of acquiring from wrists. The signal sensed from wrists has worse quality (2) when the subject is squatting and dumbbells lifting. Worse quality is caused by greater movements of electrodes and lead set attached to hands than in case of chest electrodes. From this follows, that sensing from chest gives better results. None of the acquired signals (from any person and exercise) was evaluated as worse quality (3).

Performing a visual verification, we have found that the algorithm [7] fails when the evaluated signal is trimmed. Due to the limited voltage range of BITalino, signal is trimmed when the subject is walking, squatting and standing up and sitting down. According to visual verification of two experts, signal quality is of 2 when signals are acquired while the subject is walking and 3 while the subject is squatting and standing up and sitting down.

Electrodes placement	Exercise	Signal quality [%]											
		1 (low noise)				2 (medium noise)				3 (high noise)			
		S1	S2	S3	∑	S1	S2	S3	∑	S1	S2	S3	∑
Chest (2)	walking	100	100	100	300	0	0	0	0	0	0	0	0
Chest (2)	squating	100	100	100	300	0	0	0	0	0	0	0	0
Chest (2)	standing up and sitting down	100	100	100	300	0	0	0	0	0	0	0	0
Chest (2)	chest rotation	100	100	100	300	0	0	0	0	0	0	0	0
Chest (2)	dumbbells lifting	100	100	100	300	0	0	0	0	0	0	0	0
Chest (2)	deep breathing	100	100	100	300	0	0	0	0	0	0	0	0
Wrist (6)	walking	100	100	100	300	0	0	0	0	0	0	0	0
Wrist (6)	squating	0	0	0	0	100	100	100	300	0	0	0	0
Wrist (6)	standing up and sitting down	0	0	100	100	100	100	0	200	0	0	0	0
Wrist (6)	chest rotation	0	100	100	200	100	0	0	100	0	0	0	0
Wrist (6)	dumbbells lifting	0	0	0	0	100	100	100	300	0	0	0	0
Wrist (6)	deep breathing	100	0	100	200	0	100	0	100	0	0	0	0

Table 3: Quality of exercise ECG (S1-S3 refer to subjects 1-3).

4. CONCLUSION

In this paper, we recommend proper conditions for ECG signal acquisition using BITalino. The sampling frequency should be set with respect to required diagnostic information. For morphology assessment f_s = 1,000 Hz is necessary. For rhythm monitoring f_s = 100 Hz is sufficient. We recommend two possibilities of electrodes placements: 1) + under right clavicula, - under left musculus pectoralis major, ref. under left clavicula; 2) + right wrist, - left wrist, ref. left wrist closer to thumb. The choice of one of these electrodes placements is individual and depends on subject´s signal magnitude. If the subject has R wave < 1.5 mV, we recommend using chest electrodes placement. If the subject has R wave > 1.5 mV, we recommend using wrist electrodes placement. If these recommendations are not followed, the R waves may be trimmed or the amplitudes may be small (such signal makes further processing difficult or even impossible). Trimming of R wave is the biggest disadvantage identified in the tested acquisition system BITalino. From the exercise ECG follows, that signal is less affected by motion when the signal is sensed from chest. The highest noise was caused by squating and dumbbells lifting in case of sensing from wrists.

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