DESIGNING SOFTWARE AND EQUIPMENT FOR STANDARD BIPOLAR LEADS TO MEASURE FULL REAL ECG SIGNALS USING BIOPAC SYSTEM

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(Received: March 8, 2018, Accepted for publication: November 12, 2018)

ABSTRACT

Biosignals are becoming more and more significant for studying the mechanism of the human body, due to the manner of generating reflect the perform of body parts. These signals can be used for obtaining useful information for studying, diagnosis and analysing. Due to the complexity of the heart anatomy, Electrocardiogram (ECG) signals consider an efficient way for observing the performance of the cardiac muscle. This paper demonstrates how full ECG signals can be measured by designing suitable software and equipment for a Biopac System, to acquire signals of the standard bipolar leads namely lead I, lead II and lead III. This new design has applied the concept of Einthoven's triangle for obtaining ECG signals in three dimensions by using 4 electrodes instead of 9 electrodes per subject in Biopac System. The result shows good acquisition of ECG signals for all leads, thereby matching within the standard heart rate 75 BPM.

KEYWORDS*: Biosignals, ECG signals, ECG components, Einthoven's triangle, Biopac System*.

INTRODUCTION

Biosignals study is a significant part for obtaining holistic information about the mechanism of human body parts (Montesdeoca-Contreras et al., 2015). Biosignals refer to both electrical and non-electrical signals that capable of being monitored from biological beings (Rangayyan, 2002). ECG signals are one of the most important electrical signals (Semmlow, 2006) that show the performance of the heart. Acquisition of full real ECG signals is crucial for detecting the disorders and abnormalities in cardiac muscle (Kohler & Orglmeister, 2002). The aim of this paper is designing software and equipment for getting full real ECG signals to be used for analysing and studying. This can be achieved by designing 4 unique electrodes instead of 9 electrodes per subject. This design applies the concept of Einthoven's triangle (BIOPAC Systems, 2012) by placing the electrodes on right ankle (┴), left ankle (+), right wrist (-) and left wrist (±). In addition to the electrodes, software is designed carefully in three channels to fit leads I, II, and III. This design simplifies the process of the acquiring ECG signals in three dimensions to be used by students of biomedical engineering, for observing the mechanism of the heart as well as using data for processing, analysing and studying.

ECG SIGNALS REVIEW
COMPONENTS OF THE ECG

The ECG is defined as the record of the electrical signals that reflects the mechanism of the heart activity (Semmlow, 2006). This activity shows a pattern of waves that give an obvious picture how the heart works. The ECG signal consists of P wave that represents the depolarization of the right and left atria. QRS complex represents the depolarization of the right and left ventricles and follows by T wave that show the repolarization of the right and left ventricles (Bocko et al., 2010), as shown in figure (1).

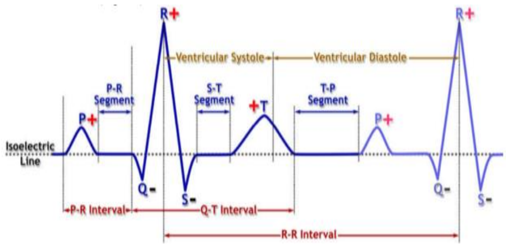

Fig.(1):- Components of the ECG signal (BIOPAC Systems, 2012).

In addition to the wave components of the ECG, there are intervals (time measurement that includes waves), and segments (time measurement that does not include waves) (Clifford & Sameni, 2010). The table (1) shows normative values from Lead II with subject heart rate 75 BPM.

Table (1):- Normative values for Components of the ECG based on resting heart rate 75 BPM (BIOPAC Systems, 2012).

ECG Component	**Normative Value : Based on resting heart rate 75 BPM**	
Waves	**Duration (sec)**	**Amplitude (mV)**
P	.07 - .18	<0.25
QRS Complex	.06 - .12	.10 - 1.5
T	.10 - .25	<0.5
Intervals	**Duration (sec)**	
P-R	.12 - .20	
Q-T	.32 - .36	
R-R	.80	
Segments	**Duration (sec)**	
P-R	.02 - .10	
S-T	< .20	
T- P	0 - .40	

LEADS PLACEMENTS

Bipolar lead is defined as two electrodes with different polarity, one positive and the other negative in addition to a third electrode dubbed (the ground). The placement of electrodes specifies the measuring orientation of signals, when going from negative to positive electrode. The ECG signals are displayed by calculating the difference (magnitude) between the positive and negative electrodes and show changes in voltage over time (BIOPAC Systems, 2012).

Willem Einthoven defined triangle called Einthoven's triangle which represents the body in three dimensions (Rivera-Ruiz et al., 2008). It consists of three leads, namely lead I, lead II, and lead III, which placed on the surface of the skin for measuring electrical activity around the heart, as shown in figure (2).

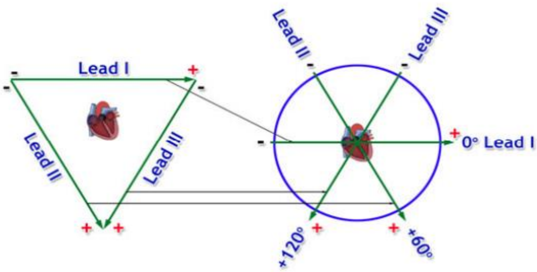

Fig.(2):- Einthoven's Triangle and standard bipolar leads (BIOPAC Systems, 2012).

Lead I – This axis is represented by place negative electrode on the right arm and positive electrode on the left arm. The lead axis is ±180˚ - 0˚.

Lead II – This axis is represented by place negative electrode on the right arm and positive electrode on the left leg. The lead axis is -120˚ - +60˚.

Lead III- This axis is represented by place negative electrode on the left arm and place positive electrode on the left leg. The lead axis is -60˚ - +120˚.

According to Einthoven (Rivera-Ruizet al., 2008), there are the relationships between the bipolar leads can be expressed mathematically as shown below, called the Einthoven's law which can be used for calculating the third lead, if values for any two leads are known.

Lead I + Lead III = Lead II

DESIGNING OF SOFTWARE AND EQUIPMENT

SOFTWARE

Software configuration in Biopac System MP36 is designed with three analog channels for acquiring signals, namely CH1 for lead I, CH2 for lead II, and CH3 for lead III, as shown in figure (3).

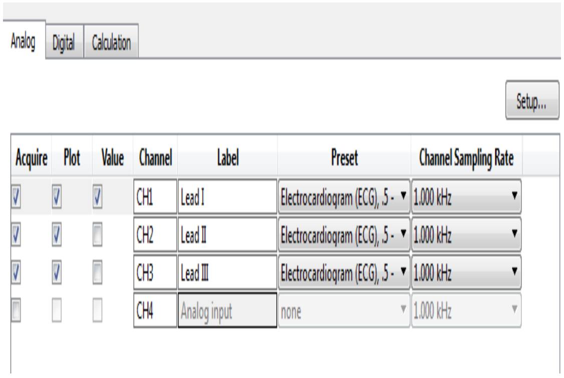

Fig.(3):- Designing process for acquisition of ECG signals.

The setup of each channel was established with parameters below:

Table (2):- Configuration of channels for each Lead.

Sample Rate	**1000 samples/sec**
Number of Samples	120000samples
Acquisition length	120 seconds
DSP Filter 1 :Low pass	66.5 Hz, Q = 0.5
DSP Filter 2 :Low pass	38.5 Hz , Q = 1
Hardware filters :High pass	0.5 Hz
DSP Filter 3 : Band stop	50 Hz, Q = 1
Gain	x1000

EQUIPMENT (HARDWARE)

A box is designed for connecting the Biopac system with electrodes and uses 4 electrodes as shown instead of 9 electrodes per subject for obtaining full ECG signals from bipolar leads. The box fully applied the concepts of Einthoven's triangle for putting electrodes on correct placement. The ground electrode placed on the right ankle, and the negative electrode placed on the right wrist. On the left ankle, the positive electrode is placed. Finally, one electrode is placed on the left wrist which works as positive electrode for Lead I, and negative electrode for Lead III, as shown in figure (4).

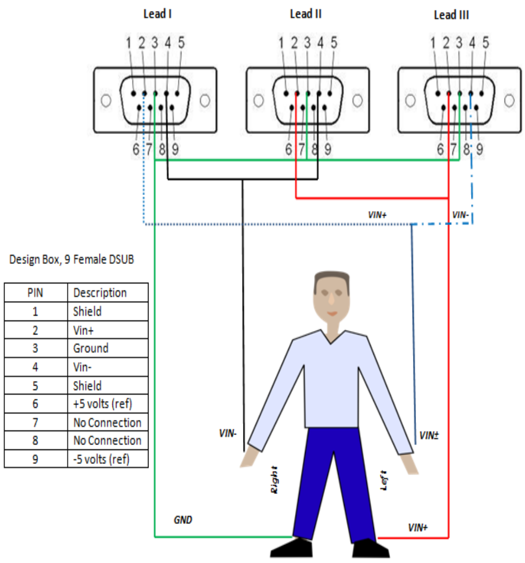

Fig.(4):- Conceptual design of 4 electrodes which place on Subject.

Fig.(5):- Physical design of 4 electrodes to connect with Biopac System.

In addition to the designing of the box, special electrodes and lead wire are designed to meet this experiment and worked perfectly with the Biopac System.

Fig.(6):- Designing Electrodes and wires to connect Biopac System with box and Subject.

The connection of the box was tested by Auto ranging Mini Multimeter device to ensure correctness of the connections.

ACQUISITION METHODS

Software and equipment were tested many times before real measurement by Mr. Martin Nguyen in Biomedical Engineering Lab, THM University, Gießen, Germany. Then, the ECG acquisition was conducted on 30 Subjects, 8 Subjects (26.67%) were female and the remaining 22 Subjects (73.33%) were male, their ages ranged from 19 to 25 years. Furthermore, the acquisition was performed in different physical conditions (supine, seated, deep breathing and after exercise) to check both signal pattern and variations in the time domain for all the leads.

Fig.(7):- Measuring full real ECG signals in seated position.

ANALYSIS AND RESULT

The acquisition of real ECG signals has been done successfully for Leads I, II, and III as shown in figure (8).

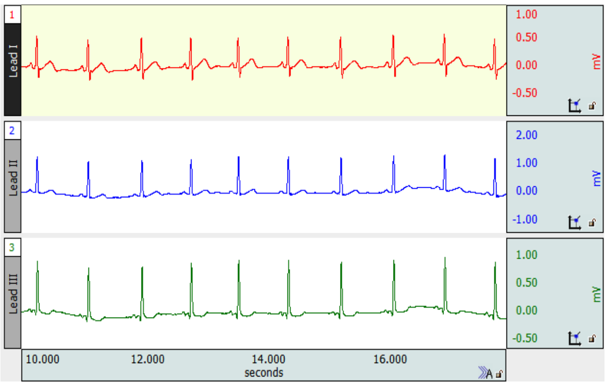

Fig.(8):- Real ECG signals for Leads I,II, and III.

The results were analyzed for 30 Subjects by Biopac System and compared based on standard heart rate 75 BPM. The ECG component, intervals and segments are measured using 3 cardiac cycles to obtain an accurate mean of value. The table (3) shows the ECG components, intervals and segments for all Subjects.

Table (3):- Results of ECG components in time domain for all Subjects.

Normative Value Based on Heart Rate 75 BPM									
	ECG Component Duration (sec)			Intervals Duration (sec)			Segments Duration (sec)		
	Mean of P	Mean of QRS	Mean of T	Mean of P-R	Mean of Q-T	Mean of R-R	Mean of P-R	Mean of S-T	Mean of T-P
Subjects	**.07 - .18**	**.06 - .12**	**.10 - .25**	**.12 - .20**	**.32 - .36**	**.80**	**.02 - .10**	**<.20**	**0 - .40**
1	0.0903	0.0817	0.191	0.133	0.348	0.807	0.0437	0.084	0.329
2	0.132	0.125	0.176	0.157	0.34	0.772	0.041	0.066	0.289
3	0.095	0.114	0.191	0.134	0.317	0.859	0.048	0.143	0.377
4	0.122	0.097	0.173	0.109	0.352	0.851	0.087	0.074	0.296
5	0.098	0.118	0.175	0.13	0.375	0.907	0.062	0.116	0.391
6	0.098	0.097	0.161	0.131	0.359	0.781	0.037	0.083	0.271
7	0.136	0.087	0.182	0.125	0.35	0.895	0.096	0.083	0.34
8	0.08	0.11	0.112	0.135	0.318	0.559	0.033	0.055	0.105
9	0.115	0.091	0.202	0.102	0.367	0.839	0.092	0.085	0.267
10	0.094	0.1	0.14	0.165	0.313	0.508	0.073	0.073	0.033
11	0.083	0.096	0.13	0.141	0.337	0.765	0.055	0.101	0.29
12	0.075	0.091	0.135	0.134	0.34	0.726	0.041	0.093	0.24
13	0.108	0.119	0.180	0.14	0.344	0.834	0.05	0.108	0.352
14	0.079	0.095	0.114	0.132	0.301	0.734	0.032	0.065	0.105
15	0.074	0.094	0.126	0.135	0.326	0.756	0.042	0.086	0.211
16	0.109	0.105	0.17	0.129	0.347	0.822	0.035	0.096	0.311
17	0.098	0.096	0.154	0.134	0.365	0.763	0.035	0.105	0.267
18	0.087	0.092	0.16	0.132	0.366	0.742	0.043	0.05	0.236
19	0.092	0.089	0.158	0.197	0.361	0.843	0.082	0.075	0.277
20	0.109	0.104	0.161	0.221	0.338	0.874	0.083	0.094	0.331
21	0.098	0.094	0.177	0.189	0.354	0.893	0.089	0.077	0.323
22	0.099	0.095	0.165	0.202	0.351	0.852	0.084	0.082	0.310
23	0.068	0.091	0.111	0.128	0.301	0.595	0.048	0.099	0.168
24	0.071	0.108	0.111	0.117	0.304	0.603	0.061	0.094	0.182
25	0.077	0.105	0.138	0.131	0.301	0.624	0.051	0.098	0.188
26	0.072	0.101	0.12	0.125	0.302	0.655	0.053	0.097	0.179
27	0.094	0.089	0.159	0.191	0.321	0.689	0.094	0.082	0.178
28	0.083	0.08	0.128	0.19	0.325	0.687	0.097	0.087	0.186
29	0.065	0.078	0.14	0.174	0.322	0.704	0.1	0.072	0.207
30	0.08	0.082	0.142	0.185	0.322	0.72	0.097	0.08	0.19

All results of the different physical conditions (supine, seated, deep breathing and after exercise) were during the standard range. The tables (4, 5, 6, and 7) show the detailed result of measurement of ECG signals in seated condition for Subject1; lead II, to give clarity how the results are measured, verified and analyzed for all Subjects.

Table (4):- Result of ECG components in time domain during seated condition for Subject 1.

ECG Component	Normative Value Based on heart rate 75 BPM	Duration (ms)measurements taken from 3 cardiac cycles)			
		1	**2**	**3**	**Mean**
Waves	Duration (sec)				
P	.07 - .18	0.089	0.093	0.089	0.0903
QRS Complex	.06 - .12	0.079	0.082	0.084	0.0817
T	.10 - .25	0.216	0.157	0.201	0.191
Intervals	Duration (sec)				
P-R	.12 - .20	0.131	0.137	0.13	0.133
Q-T	.32 - .36	0.348	0.35	0.347	0.348
R-R	.80	0.836	0.801	0.79	0.807
Segments	Duration (sec)				
P-R	.02 - .10	0.038	0.049	0.044	0.0437
S-T	< .20	0.069	0.09	0.095	0.0847
T-P	0 - .40	0.345	0.331	0.31	0.329

Table (5):- Result of ECG waves in amplitude domain during seated condition for Subject 1.

ECG Component	Normative Value Based on heart rate 75 BPM	Amplitude (mV) measurements taken from 3 cardiac cycles			
		1	2	3	Mean
Waves	Amplitude (mV)				
P	< 0.25	0.062	0.053	0.053	0.056
QRS Complex	.10 - 1.5	0.93	0.938	0.99	0.953
T	<0.5	0.075	0.067	0.066	0.069

The table (6) shows the result of Heart rate in different physical conditions. The heart rate inclines to be slower when supine, and hasten when we either sit or stand. This is a natural body response to slight drop in blood pressure with upright posture and its purpose seems to be to maintain. It also shows that heart rate is increasing in inhalation phase and decreasing in exhalation phase. This change comes due to the shifting of the mean electrical axis (Travaglini et al., 1998).

Table (6):- Heart beats measurements in different positions for Subject 1.

Condition	Heartbeats taken from 3 cardiac cycles 1	2	3	Mean
Supine	75.949	77.62	69.849	74.473
Seated	81.301	78.637	77.022	78.987
Start of inhale	71.856	85.106	75.377	77.446
Start of exhale	60.976	61.287	61.475	61.246
After exercise	111.73	107.53	103.27	107.51

The result also verified the Einthoven's law which states the magnitude of Lead II equal magnitude of Lead I + Lead III, as shown in table (7).

Table (7):- Einthoven's Law—Simulated Confirmation: Lead I + Lead III = Lead II

Lead	***Same Single Cardiac Cycle*- millivolts**
Lead I	0.544
Lead II	0.822
Lead III	0.278

This approves that software and equipment are correctly designed for obtaining full leads ECG signals that be used for diagnosis, studying and detection the disordered of the heart.

CONCLUSION

This paper shows that the designing of software and hardware for acquisition the ECG signals, was correctly performed for getting full real signals through three standard leads and 4 electrodes. This design gives a feasible method to apply the Einthoven's triangle for getting real signals within the standard range. The signals that will be acquired assist students in biomedical engineering for studying the performance of heart easily.

ACKNOWLEDGMENTS

I wish to express my thanks to Biomedical Engineering Lab for recording. I also would like to thank Martin for testing and all Subjects for participating in the acquisition of the ECG signals.

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الخلاصة

تم في هذة الدراسة تصميم برنامج و معدات مناسبة لنظام Biopac System لقياس اشارات القلب من ثلاثة جهات في اوضاع مختلفة. هذا التصميم اعتمد على مفهوم مثلثEinthoven الذي يتكون من ثلاثة محاور lead I, lead II, lead III للحصول على اشارة حقيقة تعكس الية عمل القلب. يتم ذالك من خلال وضع قطب كهربائي السالب على معصم اليد اليمنى و وضع القطب كهربائي على معصم اليد اليسرى الذي يكون سالب لـ lead III و يكون موجب لـ lead I. على كاحل الأيمن يتم وضع القطب الكهربائي الأرضي وعلى كاحل الأيسر يتم وضع القطب الكهربائي الموجب. التصميم الجديد يستخدم اربعة اقطاب كهربائية بدلا من تسعة أقطاب كهربائية لقياس اشارات القلب في نظام Biopac, وبتالي يساعد طلاب قسم الهندسة الحيوية على تعلم عملية القياس لسهولتها و كذلك استخدام أشارات القلب لغرض الدراسة والتحليل.