Analysis on MET Value Due to the Relation Between Echocardiogram (ECG) Signal and Human Physical Activities

Nabilah Ibrahim, Chai Win Ann, and Suhaila Sari

Abstract

Electrocardiogram (ECG) signal provides a lot of information about the cardiac functions through its patterns displayed. Besides to use ECG for cardiovascular diseases diagnostic function, the use of ECG has extended to wider areas such as monitoring the performance of athletes, lie detections, human authentication, stresses and emotion measurement. Moreover, from the ECG signal, the heart rate (HR), heart rate variability (HRV) and R-R intervals can be obtained and relate these physiological response value with human physical activities. Thus, the using of an electrocardiogram (ECG) device or wearable ECG monitor to diagnose the heart condition for the training performance evaluation is desirable. The result is recorded and assessed by analyzer (prototype of this project) for diagnosis. This work employs the Metabolic Equivalent Task (MET) to perform the level of physiological activities from volunteers. Any deviation from target heart rate value indicate the current physiological condition proportional to result of training level (either achieved the target already or need to add more the intensity, load, and duration of training). Thus, this work will assess and evaluate the proposed physical activity performance based on the assessment of ECG signal during exercise.

Keywords

R-R intervals • Electrocardiogram (ECG) • Circulatory system • Metabolic equivalent of task (MET)

1 Introduction

Due to the increasing numbers of people care about cardiac condition and the increase popularity of exercise especially workout/gym among society nowadays, two critical schemes can be enforced in order to ensure that low cost and qualitative health monitoring services can be delivered. However, the problem is people do not know how to carry out the training and the amount of physical activity is optimum to achieve the desired cardiac fitness state [1]. Compared to complicated fitness medical check-up procedures, the alternative method is using electrocardiogram (ECG) device or wearable ECG monitor to diagnose the heart condition for the training performance evaluation. By attach the electrode onto the skin, the portable ECG device will process the input and display the heart rhythm. The result could be recorded and analyzed by analyzer (prototype of this project) to diagnose the result in order to know better about our heart condition at own place. Any deviation from target heart rate value indicate the current physiological condition proportional to result of training level (either achieved the target already or need to add more the intensity, load and duration of training). This is because the different purpose of training would result in different heart rate variability

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T. Vo Van et al. (eds.), *6th International Conference on the Development of Biomedical Engineering in Vietnam (BME6)*, IFMBE Proceedings 63, https://doi.org/10.1007/978-981-10-4361-1_5

(HRV) [2]. Thus, in this project, the cardiac analyzer is designed to monitor and evaluate the physical activity performance based on the assessment of ECG signal during exercise.

2 Experimental Method

2.1 Data Acquisition Phase

In order to achieve the purpose of project, the project is carried out in three different phases which are data acquisition phase, data analysis phase and prototype construction phase respectively. The overview of procedure is 10 healthy young males aged between 20 to 25 years old are selected to undergo stress test for ECG signal data collection, then the collected ECG signals are analyzed and lastly the analyzed data is utilized into microcontroller to produce the functional cardiac analyzer for athletes physical activity performance evaluation.

The healthy young males are chosen as subject in this project is due to the project is physiological-based, focus on physiological response that will reflect the performance especially in athletes but not to identify the abnormal heart rhythm (possible cardiac disease) as in pathological study. The data collection phase is carried out at UTHM medical center. The equipment needed such as ECG device and treadmill are requested from UTHM medical center. Besides that, the assistance obtained from nurses during ECG signal acquiring and consultation with cardiology doctor about the diagnosis of ECG waveform. Table 1 shows the 10 healthy young males (volunteers), divided into two groups according to level of physical activity. The physical activity questionnaire to be filled by subjects consists of questions about the physical activity type, the amount of days in a week and the duration in minutes per day for carrying out physical activity. Then the level of physical activity (MET minutes/week) is calculated from the intensity of exercise activity (MET value with respect to different exercise, refer to MET table) and the duration (minutes/week) done by the subjects in the recent 1 month prior to stress test.

Stress test is carried out by each subject. Exercise stress test is a test of cardiovascular fitness made by monitoring the heart rhythm during the period of increasingly strenuous exercise. Smoking, intake of stimulant drinks (tea, coffee, caffeine containing soft drinks) and intake of medication drugs are not allowed 1 h prior to the stress test. The exercise stress test in this project involves running on treadmill for 1 km distance and speed is set as 5.0 initially then increase to and maintain as 10.0. The treadmill used is MATRIX model. The recording of subject's ECG is taken place before and after the exercise as pre and post ECG signal. The duration for stress test is approximately 20 min including the ECG recording time and exercise time.

In the assessment of ECG signal, the conventional 12-lead ECG system is used. The term "lead" in context of ECG refer to voltage difference between two electrodes and this difference is recorded as signal by ECG device. The ECG device used in this project is Kenz-Cardico 302 model consists of 10 surface electrodes, 1 monitor screen with panel and several cables. The electrodes need to be placed at correct position to obtain the optimum result. The subject is in the lying position during the measurement of ECG.

Figure 1 shows the figure of subject 4 conducting the stress test on treadmill.

2.2 Data Analysis Phase

Since ECG signal is in analog form, it is difficult to handle by software and utilized in microcontroller. Analog signal has to converted into digital form before utilize it. The heart rate variability which is R-R interval from ECG signal is selected to do the further analysis as heart rate variability represents the physiologic and psychological health. The analysis result of R-R interval will be used to determine whether regular exercise increases heart rate variability and

Table 1 List of 10 subjects and details

Subject number	Age	Height (cm)	Mass (kg)	Body mass index (BMI)
Subject 1	22	183.0	77.0	23.0
Subject 2	24	165.5	67.5	24.6
Subject 3	25	166.5	57.7	20.8
Subject 4	22	167.0	68.0	24.4
Subject 5	21	166.5	70.0	25.3
Subject 6	23	172.5	66.0	22.2
Subject 7	23	174.5	75.0	24.6
Subject 8	23	167.5	62.0	22.1
Subject 9	23	175.5	65.0	21.1
Subject 10	23	189.0	75.0	21.0

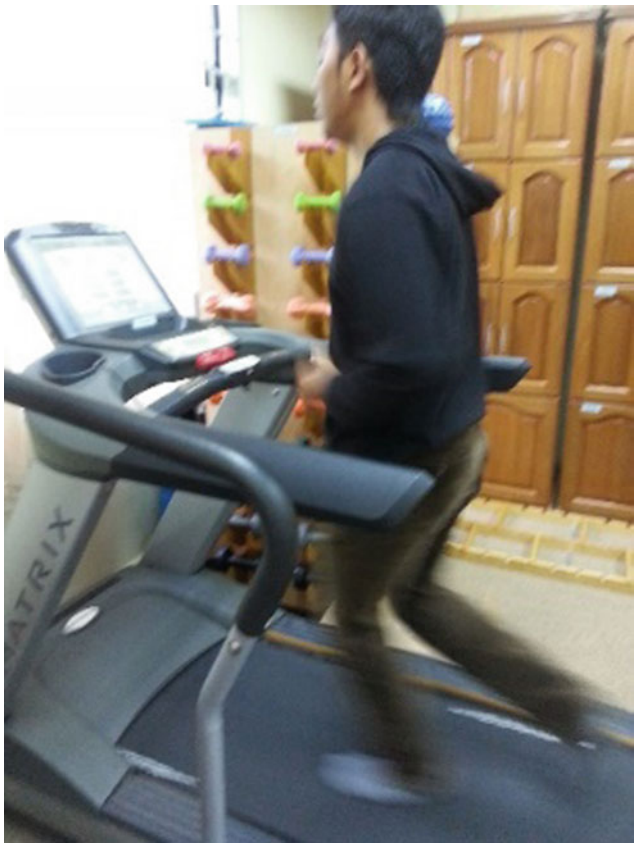

Fig. 1 Subject 4 running on the treadmill during the stress test

the minimum amount of exercise is required to improve HRV and health. There are 12 ECG signals shown on the ECG result paper which are leads I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5 and V6 [1]. The ECG signal from lead II is taken to do analysis due to the suggestion of PKU cardiology doctor. The explanation is lead II is look at electrical activity from the vantage point of inferior surface, its signal is closest to the shape of real ECG waveform and most of the single-lead ECG system use lead II electrode placement to get the ECG signal. ECG paper is paper full with grids of small and large squares. The recording speed of ECG is 25 mm/second, hence each small square represents 0.04 s (40 ms) in time along horizontal axis and each larger square contains 5 small squares representing 0.2 s (200 ms). In other words, ECG paper can be perceived as a graph, electrical activity is plotted on vertical axis (10 mm/mV) against time on horizontal axis (25 mm/s), easy for heart rate variability (R-R interval) calculation [2].

$$\begin{aligned}\text{R-R interval (s)} &= \text{(i)}\ 0.04\text{s} * \text{number of small squares} \\ &= \text{(ii)}\ \frac{\text{number of small squares (1mm)}}{25\text{mm}} * 1\text{s}\end{aligned} \tag{1}$$

$$\text{Average R-R interval (s)} = \frac{\text{RR1} + \text{RR2} + \text{RR3} + \text{RR4} + \text{RR5} + \text{RR6} + \text{RR7} + \text{RR8} + \text{RR9} + \text{RR10}}{10} \tag{2}$$

*average R-R interval is required and calculated to obtain the overall R-R interval in ECG signal.

MET minutes/week = MET value (intensity refer to MET table)*minutes for exercise*days

Example: Jogging (MET = 10.0) carried out for 1 h in 3 days per week

$$\begin{aligned}\text{MET minutes/week} &= 10.0 * 60\,\text{minutes} * 3 \\ &= 1800\end{aligned} \tag{3}$$

MET minutes/week from the combination of exercise and difference in duration also can be calculated.

Example: slow swimming (MET = 4.5) for 30 min in 2 days per week + no load hiking (MET = 6.9) for 1 h in 1 day per week

$$\begin{aligned}\text{MET minutes/week} &= (4.5 * 30 * 2) + (6.9 * 60 * 1) \\ &= 270 + 414 \\ &= 684\end{aligned} \tag{4}$$

The relationship between R-R interval and metabolic equivalence minutes per week (MET) is analyzed by using regression. Regression is a quantitative analysis that establish relationships and make it possible to predict the potential one or more variables in term of others, hence it is very suitable to use regression in predict the value of R-R interval which varies with MET. Besides that, it is very easy to carry out the regression analysis and the result is understandable. The ANOVA test also include in the regression analysis, the result will come out with regression graph and AVOVA table. Both ANOVA and T-test are known as hypothesis testing or significance testing. It allows to draw conclusions or make decisions regarding population/category from sample data. *P* value less than 0.05 is considered significant different between groups [11].

2.3 Prototype Construction Phase

Arduino UNO is a robust 16 MHz microcontroller board which consists of 2 kb of ram, 32 kb of flash memory for storing program, 1 kb of eeprom for storing parameters, 14 digital input/output pins, 6 analog input pins, a usb connection, a power jack and a reset button. Arduino UNO is chosen in this project are due to its wide range of applications, low cost, high quality, small size, easy to program and re-programming, availability analog and digital input/output pins. The role of arduino UNO in this project is to receive

the input value from the 4 × 4 matrix keypad, carry out the analysis task then transfer the result to the output pins which is connected to 20 × 4 lcd (lm044 l) for display.

There are three types of computer languages can be used as instruction set in microcontroller programming which are machine code, assembly language and high-level language. Arduino IDE is used in this project to create program code to instruct the microcontroller Arduino UNO in carrying out the specific task which is cardiac analyzer function. The programming language used is Arduino language. Before develop the program coding, the algorithm must be built so that the flow in program can be seen clearly, enable the later coding design become easier (Figs. 2 and 3).

The reason of choosing the Arduino as microcontroller used in this project to produce target heart rate analyzer is due to its many advantages and superior points compared to other microcontroller types. First, the Arduino UNO is simple and easy board to use with as mentioned above. Unlike the other microcontrollers or dev boards which normally are complex in structure with a lot of add-on parts on board such as LCDs, LEDs, buttons, 7-segments or more, Arduino UNO only have the basic structure and just add external shield if required. Some people may perceive that it is a disadvantage to have simple board structure but sometimes the more do not mean the best but instead make one become more complicated. Second, Arduino IDE is a completely open-source software. It is free to download the IDE with its supplements such as libraries and gcc (GNU compiler collection) tool and allowed for sharing. There are tons of object-wrapped libraries extractable in IDE to carry out various purposes include LCD display, internet connection, motor control and many more. Unlike some microcontrollers manufactured by specific company which are not open-source based, hence their source are limited and even need to pay for download and utilization due to license issues. Moreover, they have their own special languages, libraries and compiler to differentiate them from other microcontrollers in the marker, hence sometimes not compatible and cannot use in other microcontroller (Figs. 4, 5 and 6).

3 Results

Several results are came out based on the two main purposes of the project which are firstly, to assess the relationship between Electrocardiogram (ECG) signal and human physical activity; secondly, to determine the amount and types of physical activity required to achieve the cardiac fitness state (target heart rate).

The ECG results as shown in Fig. 7 is obtained from subject 4 represents athlete males group and ECG result in Fig. 8 is obtained from subject 6 in normal males group. The pre-ECG test is carried out before the exercise stress test (running on the treadmill) to identify the normal cardiac activity (normal ECG signal). While post-ECG test is carried out after the exercise stress test to identify the difference or change in ECG signal brought by the exercise. There are

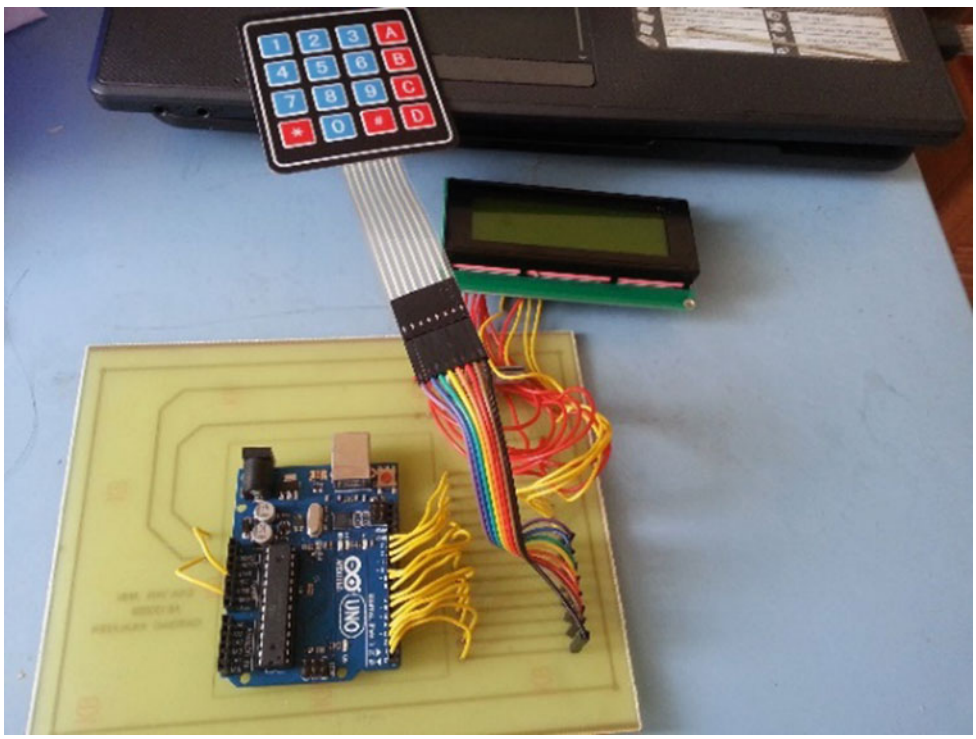

Fig. 2 PCB view from component side

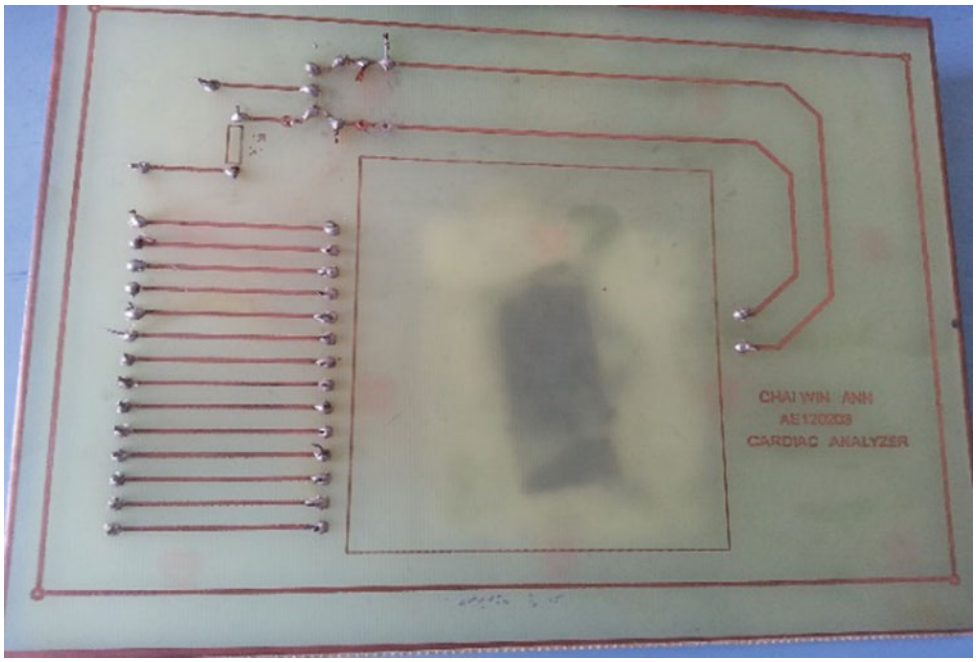

Fig. 3 PCB view from track side

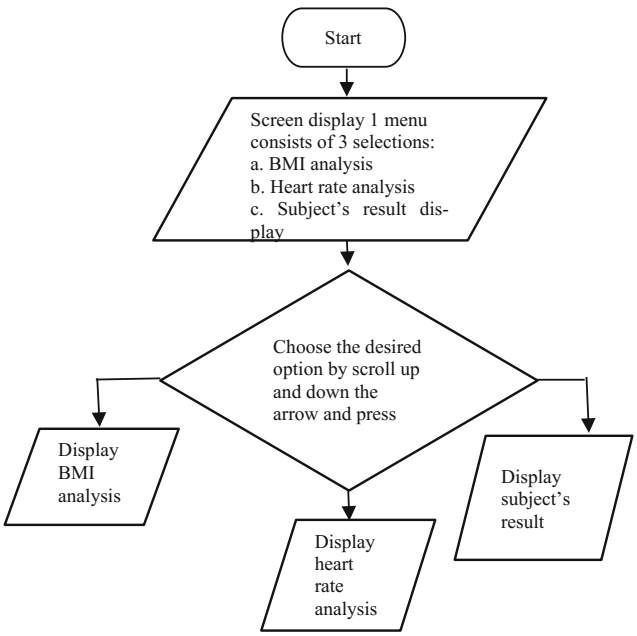

Fig. 4 Algorithm of menu operation

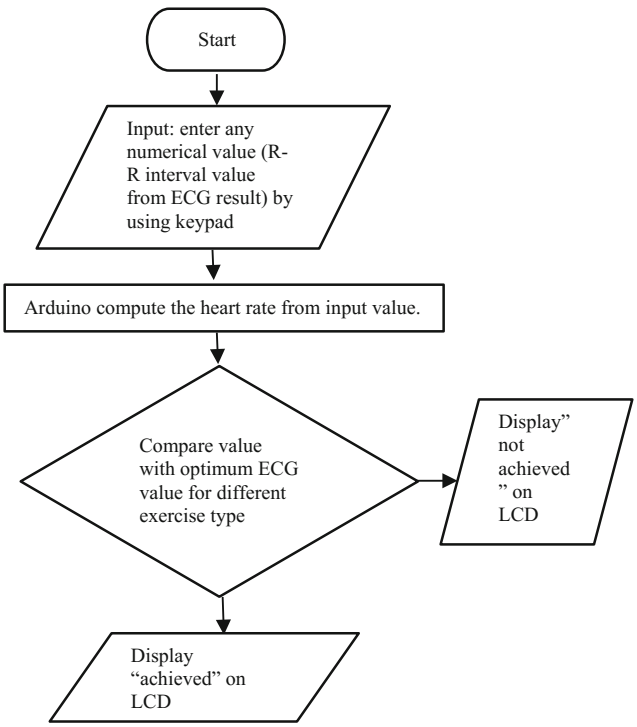

Fig. 5 Algorithm of target heart rate analysis operation

significant difference and change of ECG signal between pre- and post-test in two groups respectively. Compared to pre-test result, the ECG signal of post-test shows a faster moving P waves, QRS complex and T wave, more waveforms in a specific of time are formed in both groups [3]. This is because large amount of oxygen is needed for production of ATP energy (conversion of Adenosine Diphosphate-ADP into Adenosine Triphosphate-ATP energy is an aerobic reaction) at muscle site during exercise. Hence, cardiac muscle have to systole and diastole more to distribute the oxygenated blood to muscle site, carry away the deoxygenated blood and return to lungs for gaseous exchange through cardiovascular system [4]. Simply to say that there are direct linear relationship between cardiac activity (systole and diastole) and the human physical

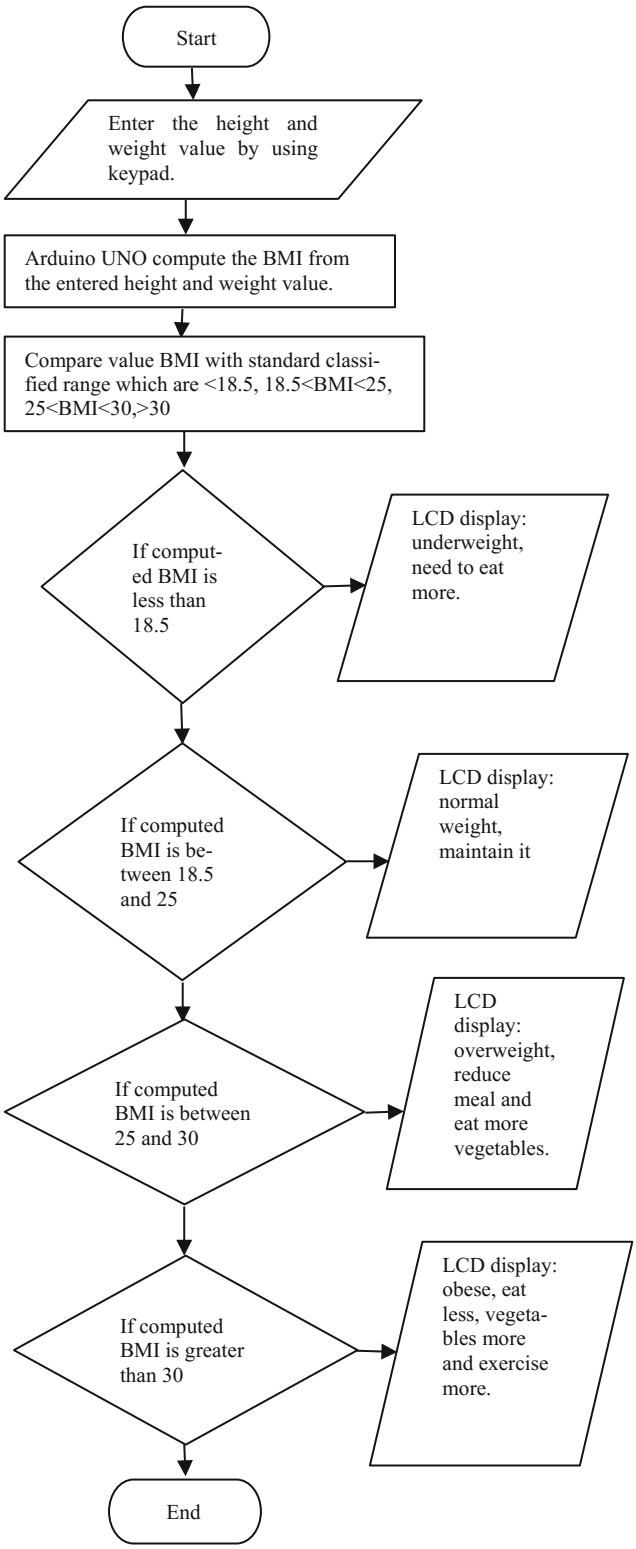

Fig. 6 Algorithm of BMI analysis operation

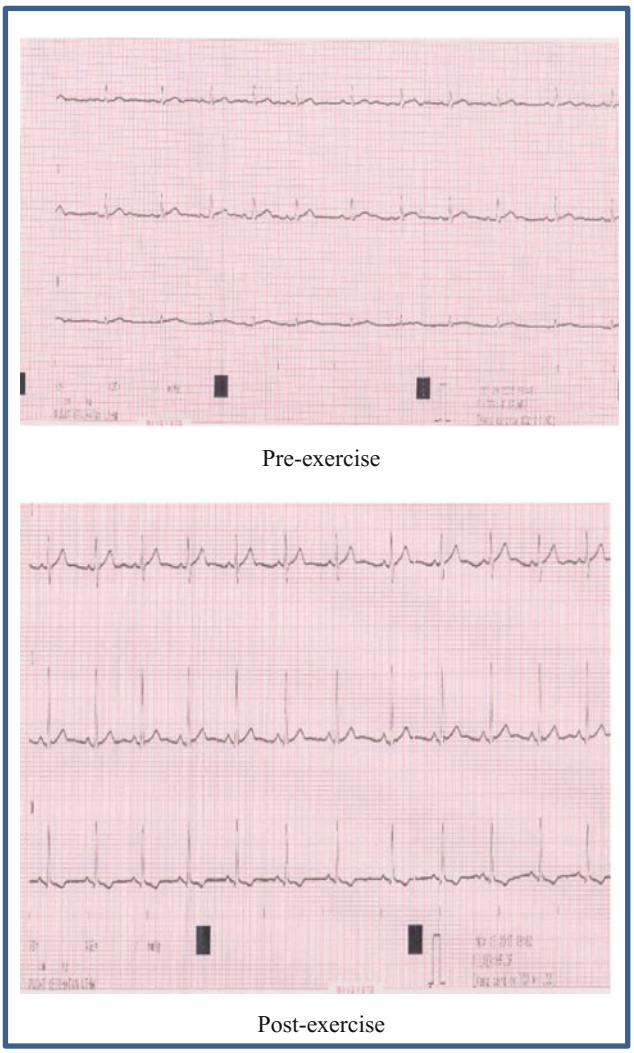

Fig. 7 ECG result from one of the subject in the athlete group

activities. The more vigorous of exercise, the faster change of ECG signal or heart beat rate.

Besides to the fast change of ECG signal observed from the both groups' results, another one important feature can also be observed from the ECG results. Although there are increase in heart rate and rhythm in both group during exercise stress test, it can be seen that athlete males group have little increase in heart rhythm than normal males group who have dramatic increase in heart rate by comparing ECG results of both groups (normal and athlete males groups). Athlete males group have steady heart rate than normal males group during exercise. The reason is people who exercise regularly have strong and elastic cardiovascular

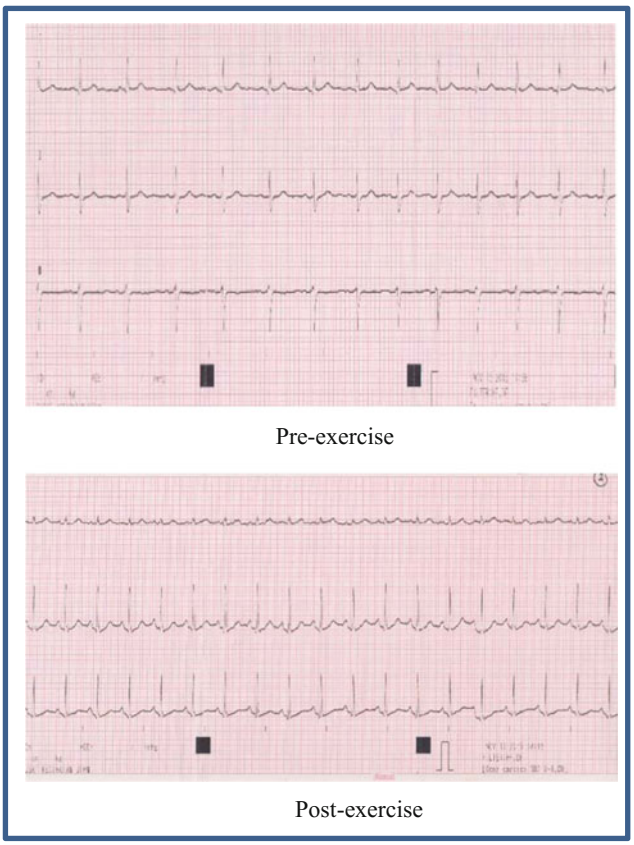

Fig. 8 ECG result from one of the subject in the normal group

system. There are free or less of cholesterol and fat plaque in the lining of the blood vessel's wall resulting in wider space and elastic vascular [5]. Since the cardiac muscle and blood vessels are strong and elastic, large amount of oxygenated blood could be pump in one time resulting in steady systole and diastole of cardiac to satisfy the need of muscle during exercise. On the other hand, the cardiovascular system of less exercise people is not as strong and elastic as regular exercise people due to accumulated of cholesterol and fat plaque on the wall lining, only small volume of oxygenated blood could be pumped through the narrow blood vessels, hence need more cardiac systole and diastole to cater the need. As a conclusion, regular physical activities affect and benefit much to the cardiovascular system. People are encouraged to exercise regularly for the sake of cardiac fitness.

ECG results are the direct result obtained from the subjects during exercise stress test. Some useful information can be interpreted from ECG signal. In order to confirm the linear relationship between ECG signal and physical activities by using more reliable and scientific method, the statistics analysis include regression, ANOVA test and T-test. All statistics analysis are done by Microsoft Excel software [11] (Fig. 9).

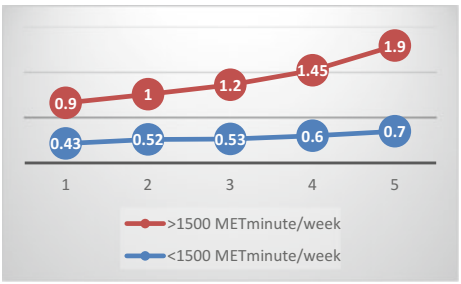

Fig. 9 The relationship between heart rate variability (RR interval) and MET minutes/week

Anova: Single Factor

SUMMARY				
Groups	Count	Sum	Average	Variance
<1500	5	2.78	0.556	0.01
>1500	5	6.45	1.29	0.16
ANOVA				
Source of variation	SS	df	MS	F
Between groups	1.3469	1	1.3469	15.787
Within groups	0.6825	8	0.0853	
Total	2.029	9		

All results clearly shown that the average R-R interval of ECG signal increases proportionally to MET value. The higher of MET value, the longer of average R-R interval. Hence, the result obtained prove that there are linear relationship between ECG signal and human physical activity.

MET value is corresponding to amount of physical activity carried out by subject in their daily life [7]. It reflects the lifestyle of people and always used as parameters to indicate active lifestyle or sedentary lifestyle. While R-R interval is the interval between two ventricle depolarization in cardiac cycle [12]. Hence, R-R interval can be used to indicate the heart rate.

Athlete males are in the group of MET >1500 and normal males are in the group of MET <1500. The reason of choosing two distinct groups in term of MET value is to enable see more clearly the effect of physical activity toward cardiac. From the result, there can be seen that higher average R-R interval in the MET >1500 group compared to MET <1500 group. Higher average R-R interval means that the heart beat rate is steady increase and not increase dramatically. In addition to that, the result of T-test $P = 0.0041$ which is less than 0.05 show that there is a significant difference between 2 category (<1500 MET and >1500 MET) [11]. The production of such result from statistics analysis is satisfy the direct interpretation from the observation of ECG result which is more active group who exercise regularly own stronger cardiovascular system.

4 Discussions

The parameters such as accuracy, precision, noise, signal to noise ratio and safety need to be considered in obtaining ECG result during exercise stress test. Accuracy is the closeness of measurement to the actual value and precision is the proximity of repeat measurements to each other. While noise is undesirable signal that interfere the desired signal and signal to noise ratio is the ratio of useful signal to the background noise/interference. Therefore, the optimum result is the result which is accurate, high signal to noise ratio, least noise and highly precise. In order to achieve all optimum parameters, it is very important in preparation, proper utilizing the ECG device, proper methods in carrying out the test and calibration.

Types of noise may occur during ECG test need to be identified and eliminate them for more accurate and precise result. Three main noises are come from AC interference, muscle tremor, and baseline drift [15]. AC interference is part of electricity produced by electrical wire due to current leakage, electrostatic and magnetic induction which tends to cause interference. To reduce AC interference, avoid using the ECG device nearby other electronic medical instruments such as X-ray and ultrasound machine (should be turn off), ground the ECG properly, tighten the electrode with its lead and set the digital filter for AC interference.

BMI analysis is a reliable indication whether a person has too much body fat by calculate the ratio of weight (kg) to square height (m). There becomes close related between body fat and cardiac condition. The common phenomenon is overweight or obesity population have a higher risk of unfitness cardiac. Their heart rate will become unusually fast during exercise (even is light exercise). This is because their cardiac muscle and blood vessels are surrounded by thick fat layer, have to pump harder to satisfy the blood needed. Thus, the physical exercise is encouraged to improve the cardiac fitness as exercise will reduce the fat and cholesterol plaque and boost the cardiovascular muscle. Besides, another significant factor affect the body fat is food habit. Hence BMI analysis designed in this target heart rate analyzer include the calculation of BMI and suitable exercise and food suggestion based on the BMI value.

5 Conclusions

ECG signal is a reflection of heart activity, hence the result of ECG signal can be interpreted and relate it to human physical activities in order to prove the relationship between cardiovascular system and physical exercises to improve the cardiovascular system. As a conclusion, there is a linear relationship between cardiac fitness state and the regularly exercises.

After knowing the regular exercises bring benefits to our cardiovascular system (reduce fat plaque on the lining, increase the elasticity of cardiovascular muscle and provide more steady heart rate) through the study and analysis in this project, a cardiac analyzer is designed and constructed to carry out the comprehensive analysis during physical exercises. The comprehensive analysis include heart rate analysis (to analyze whether achieve the target heart rate or not), BMI analysis (to analyze the body fat, provide optimum food and exercise suggestion) and subject analysis.

Acknowledgments This work is sponsored by Multi-Disciplinary Research (MDR) Vot: U091, Universiti Tun Hussein Onn Malaysia.

References

1. Price DD How to read an Electrocardiogram (ECG). Basic Principles of the ECG, 20–25, Apr 2012
2. Mary Boudreau Conover (1996) Wellems syndrome in understanding electrocardiography, Mosby
3. Kin A (2000) ECG signal related with cardiac activity
4. Genovesis S, Zaccaria D (2007) Effects of exercise training on heart rate. Europace 9(1):55–60
5. Moody GB (1992) ECG-based indices of physical activity
6. Gupta N, Gupta V, Gupta K (2014) A study of effect of physical activity on autonomic functions assessed by frequency domain of HRV in healthy young males. Int J Basic Appl Med Sci 4(3):44–48
7. Christianne de Faria Coelho-Ravagnani Estimation of the metabolic equivalent (MET) of an exercise protocol. Exer Sport Sci 19
8. Rompelman O, Janssen RJ (1982) Use of phase spectral information in assessment of frequency content of ECG waveform. 129:679
9. Jaanus Lass KM (1997) Measurement of correlation between heart rate and physiological parameter variations
10. Samuel Kim MLL (2011) Modeling high level description of real life physical activities using multimodal sensor signal
11. Douglas C. Montgomery, George C. Runger (2007) Engineering Statistics, Wiley
12. Vainoras A, Jurkonis V (2008) Complexity assessment of ECG RR interval. In: Computers in cardiology, 2008
13. Chan HL, Lin CH, Ko YL (2003) Segmentation of heart rate variability in different physical activities
14. Durfee W (2011) Arduino Microcontroller Guide, University of Minnesota
15. Suzuken Co.Ltd, Kenz-cardico 302 Operation Manual, Japan
16. Malik D C++ Programming From Problem Analysis to Program Design Course Technology, Cengage Learning, Massachusetts
17. Advanced circuits Inc. (2009) Building a printed circuit board