Development of Portable Biofeedback Devices for Sport Applications

Zulkifli Ahmad and Tan Choon Mong

Abstract The purpose of this project was to propose a portable low-cost ECG and EMG devices that play the role of continuous monitoring of the user heart rate and muscle activity. Collecting and analysis of biological signal like Electrocardiography (ECG) and Electromyography (EMG) are important in the field of healthcare and sports which enable to assess the physiological state and training progress of athlete. Heart rate can reflect individual natural fitness, whereas the EMG signal indicates muscle activation and fatigue level, thus determining the performance. However, most of the EMG and heart rate measuring tools are expensive and large in size. The process of data collection also often confined to hospital or biomechanics laboratory. Therefore, this monitoring system is capable to provide an immediate feedback on physiological data due to the small size and portable for outdoor activities especially for athlete and trainers. The monitoring system is merging together between pulse and muscle sensors which function to measure the heartbeat and muscle activity respectively. Arduino Uno acts as microcontroller to analyze the collected signal and then transmits the data via Bluetooth to Android-based smartphone; laptop through Processing software; or LCD screen. Processing software was used to perform an obtained data in the graphical views.The pulse sensor applies photoplethysmography (PPG) technique to measure the heart rate in beats per minute (bpm). On the other hand, the EMG signal will be collected by passive electrode which allows the monitoring of user muscle stress. In order to validated the result, the pulse sensor result collected via Coolterm application was compared to radial pulse and Treadmill. The result showed that the error rate of the device is negligible and promising.

Keywords Electrocardiography (ECG) · Electromyography (EMG) · Microcontroller · Athlete

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1 Introduction

Basically, electrocardiography (ECG) and surface electromyography (EMG) are noninvasive technique and monitoring tools for the detection and measurement of heartbeat and EMG signal. Biosignals of ECG and EMG not only play an important role in patient health monitoring but also assess the physiological state of athlete in training progress.

ECG is used to evaluate the cardiac abnormalities and detect how fast your heart is beating [1], whereas EMG is used to analyze the muscle activity by recording the electrical activity produced by skeletal muscle during muscle contraction and relaxation cycle [2]. In modern life, both techniques have increasing importance in sports for biomechanical analysis. The data heart rate capable provide good indicators of exercise intensity and fitness respectively by inform athlete about his healthy and effective exercise behavior [3]. Surface EMG can help to understand the muscle activation in specific movement which may lead to healthy training by improving the utilization of muscle and preventing the risk of injury [2].

The conventional ECG and EMG tools were expensive and bulky. Therefore, the experiment was confined in hospital or biomechanical laboratory. Besides this, both measurement methods were using conductive electrodes which directly attached to the skin with the help of gel. These kind of method was not reusable and troublesome where not optimal for long term used as a result of surface degradation of the electrode and require the cleaning of target muscle [4].

Such situation has led to certain need for lower-cost, user-friendly, and portable heart rate detector and muscle activity detector in order to achieve the purpose of continuously monitoring the athlete physiological information [5]. In the sport domain, there is a trend to personal monitoring. Thus, there is a growing need for solution to record and analyze the biosignal on mobile devices. Hence, with the help of Bluetooth module, the data collected were transmitted to Android-based smartphone for further analysis.

2 Device Development

Figure 1 shows an overview of the device system monitoring. This project is proposed to develop a system by using Arduino Uno as microcontroller to perform analog-to-digital (A/D) process. It is compatible for both pulse and muscle sensors to detect and measure the heartbeat and muscle activity, respectively.

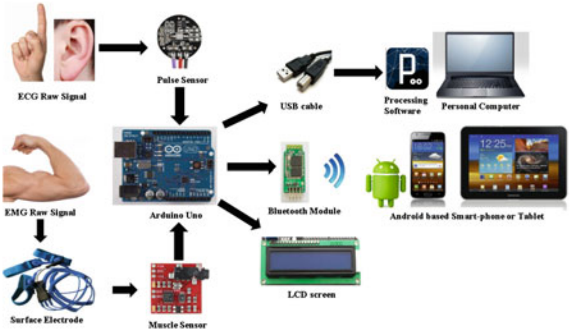


Fig. 1 An overview of the device system

2.1 *Electrocardiography (ECG)*

For ECG application, the pulse sensor was chosen which applied the photoplethysmography (PPG) technology to measure the heartbeat. Basically, PPG is an inexpensive and less power-consuming optical technique which measures the blood volume change in the vascular tissue [6]. PPG is preferred in the portable design due to small size and without precise positioning the sensor on subject body compared with conventional ECG. Pulse sensor is in reflectance mode where the photodetector sensor and LED are placed on the same side of the tissue. The pulse sensor work by green light shining into veins and a light source measure the reflected light and convert into an analog voltage. The size of the pulse sensor is small with a diameter of 15 mm only.

2.2 *Electromyography (EMG)*

In contrast, muscle sensor was applied as EMG system. The muscle sensor include surface electrode which attach on target muscle will collect the raw EMG signal to muscle sensor shield. The electrode measures the voltage difference which is generated by muscle activation. The muscle sensor then amplifies, filters, and rectifies the raw signal from human muscle and sends it to Arduino Uno. In the application of muscle sensor, the strength of muscle contraction corresponds to the amount of voltage output, which means the voltage output depends on the amount of activation in the targeted muscle.

There are three platforms to display the collected data. Firstly, it can be displayed in personal computer (PC) via Processing and Simplot programming interface. Second, with the help of Bluetooth module, the data are transmitted to Android-based smartphone wirelessly via Blueterm app. Lastly, the data also can be displayed in LCD directly after connecting with the Arduino Uno.

The systems have considerable portability due to low weight and small size of component. Moreover, the battery of lithium–polymer (Li-Po) was chosen to act as a power source for the system due to consist rechargeable feature. Furthermore, the Arduino Uno is chosen as microcontroller because it is a device with compact size that has the capability of high-speed analog-to-digital conversion as well as low cost. For wireless technology of communication, the Bluetooth module was used in the transmission of heartbeat and muscle activity data due to its low cost and small size. Meanwhile, the Processing software and Simplot were used to display the data from Arduino serial monitor in a graphical way. There are about five main components in the development of the system. The most expensive part is muscle sensor of the current device. However, this device is still low cost compared to the traditional ECG and EMG device from clinic or hospital whose are too expensive and cannot to be as portable.

3 Experimental Data

After setting up the connection of pulse sensor and muscle sensor to Arduino Uno, it then needs to create a platform to display the collected signal. The data which is displayed by LCD screen is same as displayed by serial monitor of Arduino board. It displays the digital value of both pulse sensor and muscle sensor data as shown in Fig. 2. Next, Processing and Simplot are open source programming language which serves as visual context by plotting the data from the microcontroller as shown in Fig. 3. Lastly, Bluetooth module is attached, which acts as a bridge between the

Fig. 2 LCD screen displaying heart rate and EMG

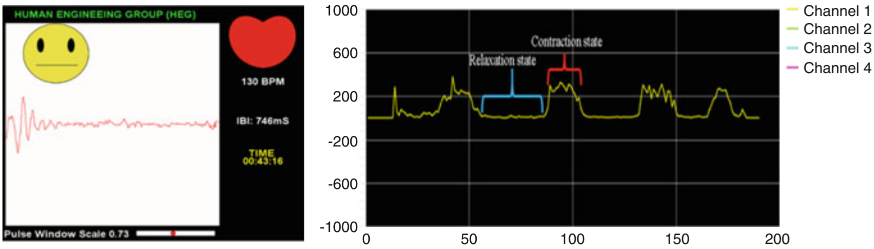


Fig. 3 Displaying heart rate (*left*) and muscle activation (*right*) via processing Programming interface

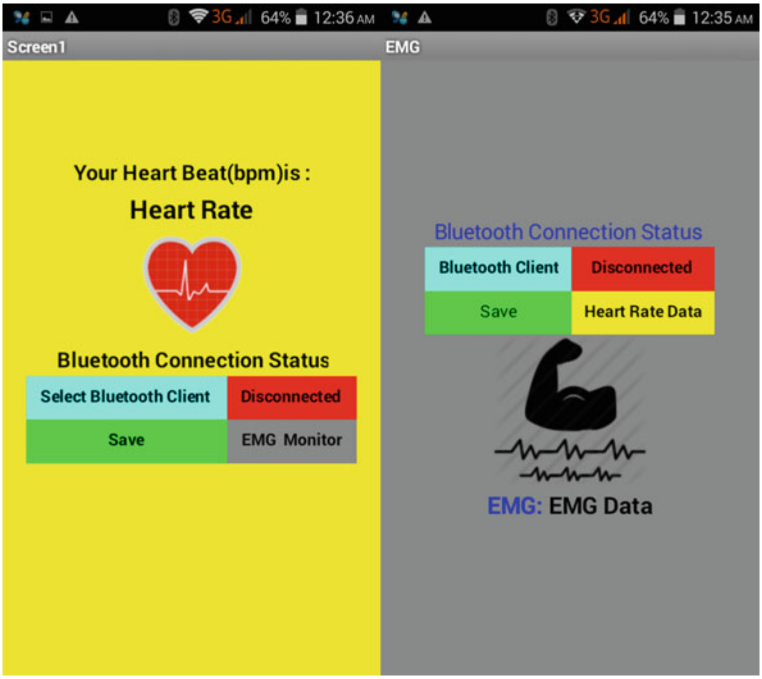


Fig. 4 Displaying EMG and heart rate data on Android phone via Blueterm app

microcontroller and Android-based smartphone. The data from microcontroller will transmit to phone wirelessly by Bluetooth module and display through Blueterm as shown in Fig. 4.

3.1 *Effectiveness Test of Pulse Sensor*

The pulse sensor is attached in finger or in earlobe to perform the measurement. Moreover, the pulse sensor does not require skin preparation as it is placed directly in contact with the skin. According to [6] stated that PPG are often attached to ear or fingertip which are single site measurement where the pulse can easily be detected. Therefore, in order to maximize the utilization of pulse sensor, the comparison between the fingertip and earlobe was conducted to identify which sites of measurement are more reliable. As shown in Fig. 5, the pulse sensor was sewing on the index finger position of glove in order to ease the user to wear the pulse sensor instead of strap it with finger. Next, a sticker is pasted on the surface of pulse sensor in order to prevent the sweaty or oily fingers affecting the signal collection. On the other hand, the second experiment was used hot glue for atttached pulse sensor on the ear clip for further measurement.

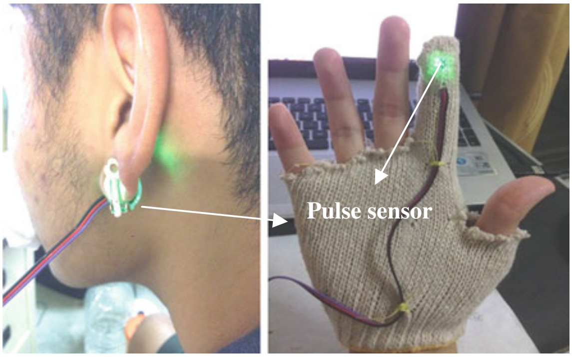


Fig. 5 Pulse sensor is clip on earlobe (*left*) and sew on glove (*right*)

3.2 *Effectiveness Test of Muscle Sensor*

There are two types of electrodes compatible with muscle sensor, which were gel surface electrode and passive electrode as shown in Figs. 6 and 7. The gel surface electrode is disposable electrode which means the electrode has limited lifetime and cannot be reused. The advantage of this electrode is can conduct under body grounding or ungrounded condition. Furthermore, gel electrode is capable of producing good quality signal and can be attached to any targeted muscle which needs to be measured. Figure 6 shows the placement of gel electrode on bicep by placing the reference electrode (black electrode) on electrically neutral tissue like bone area to ground the signal. Another two electrodes are placed on the target muscle by placing at two different points on the muscle. It was provide the point of reference for muscle activity to compare with the signal of muscle relaxation [7].

On the other hand, the passive electrode is the product of Olimex-EKG-EMG-PA. The advantage of the passive electrode is it is reusable after the measurement, but make sure that the body is in grounded condition. It means that the result will affect if the subject leg is not in land. But the passive electrode is only limited to the upper arm measurement. For the placement of

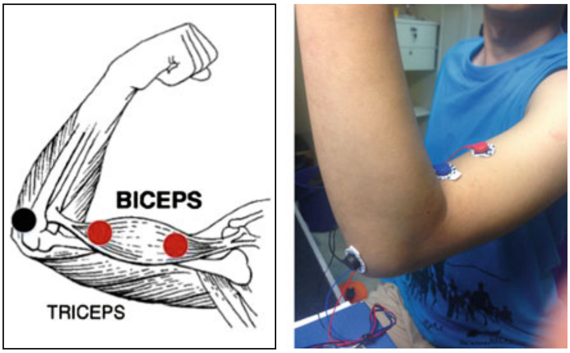


Fig. 6 EMG gel electrode placement on bicep brachii

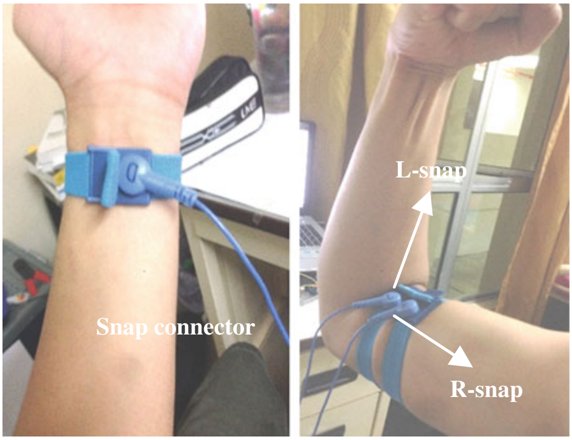


Fig. 7 Passive electrode placement on bicep brachii

passive electrode, the R snap connector is placed on the target muscle, while L snap connector is placed slightly off the center to give a point of reference for muscle activity compared to the signal of muscle relaxation. Lastly, the DLR snap connector is placed in another hand wrist to ground the signal.

4 Results and Discussion

Biofeedback device's heart rate measurement accuracy is evaluated by comparing the signal given by the sensor in finger and earlobe with manually counting the user's radial pulse. During the experiment, the user remains at sitting rest condition. Then the circuit power is switched on whereby the pulse sensor is attached on user finger. The user is requested to count their own radial pulse rate for a minute during the experiment and the signal collected from pulse sensor is save in laptop via Coolterm software. After 60 s, the simulation result which record from the Coolterm software are taken to calculate the average of heart rate value and compared with the user's final count radial pulse. The experiment procedure is repeated for ten times. After finish taking the result on fingertip, the pulse sensor was shift to user earlobe and repeated the same procedure as above The recorded result was shown in Tables 1 and 2. The error rate is calculated as equation below:

$$E = [100x|A - M|] \div A \quad (1)$$

where

E Error rate

A Actual heart rate

M Measured heart rate from pulse sensor

Table 1 Measurement of biofeedback device on fingertip and radial pulse

Test	Radial pulse (bpm)	Biofeedback device (bpm)	Error rate (%)
1	83	84.23	1.46
2	71	67.67	4.92
3	64	63.93	0.11
4	91	91	0.00
5	79	79.6	0.75
6	78	78	0.00
7	85	83.77	1.47
8	78	80.78	3.44
9	82	82.13	0.16
10	90	90.83	0.91

Table 2 Measurement of biofeedback device on earlobe and radial pulse

Test	Radial pulse (bpm)	Biofeedback device (bpm)	Error rate (%)
1	75	76.73	2.25
2	70	72	2.78
3	67	70.75	5.30
4	68	70	2.86
5	81	82.43	1.73
6	78	77.42	0.75
7	80	80.82	1.01
8	87	85.87	1.32
9	86	85.7	0.35
10	84	85.07	1.26

The comparison shows that the pulse sensor attached to fingertip has the accuracy with a mean of 1.32 and standard deviation of 1.64, while the pulse sensor attached to earlobe has the mean 1.96 and standard deviation 1.43. After the comparison of result, it was shown that the accuracy of pulse sensor attached to earlobe and finger was only slightly different, but earlobe attachment provided more reliable result.

Commercial reference pulse sensor (Spot Vital Signs Device, Welch Allyn, US) was used to test the performance of biofeedback device as shown in Fig. 8. Five subjects were tested, and simultaneous reading was taken from both devices. Average reading of 10 data is calculated as shown in Table 3.

The second experiment of running task was performed to obtain continuously changing heart rate. The subject were indicated to test on the treadmill (932i, Precor, and US) for ten minutes. Basically, the treadmill consist the feature of detect subject heart rate and are electrocardiogram accurate. The test was start by gradually increased the speed (2, 4, 6, 8 km/h) and then sharply decrease to rest [8]. The recorded results were shown in Tables 4 and 5. Measurement of pulse sensor on fingertip in running condition.

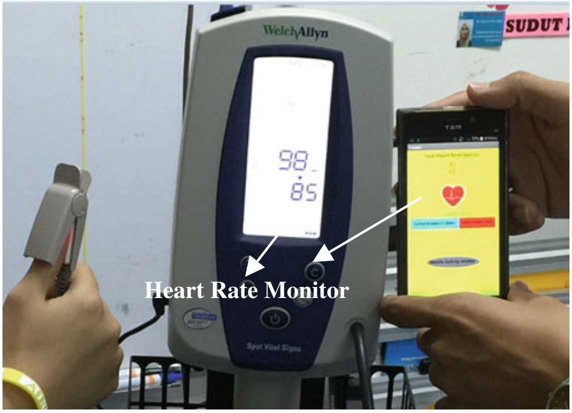


Fig. 8 Comparison of Spot Vital Signs Device and biofeedback device

Table 3 Comparison of Spot Vital Signs Device and biofeedback device

Subject	Spot Vital Signs Device (bpm)	Biofeedback device (bpm)	Error rate (%)
1	74.5	75.8	2.26
2	77.8	78.5	1.41
3	79	78	2.51
4	76.5	75.5	1.31
5	81	83	2.47

Table 4 Measurement of pulse sensor on fingertip in running condition

Speed (km/h)	Heart rate monitor (bpm)	Pulse sensor (bpm)	Error rate (%)
2	89	85	4.71
4	94	97	3.09
6	108	101	6.93
8	123	115	6.96

Table 5 Measurement of pulse sensor on earlobe in running condition

Speed (km/h)	Heart rate monitor (bpm)	Biofeedback device (bpm)	Error rate (%)
2	82	83	1.20
4	94	92	2.17
6	104	107	2.88
8	121	116	4.13

The accuracy of pulse sensor on fingertip has a mean of 5.42 and standard deviation of 1.88. On the other hand, the accuracy of pulse sensor attached to earlobe has a mean of 2.60 and standard deviation of 1.23. By gradually increasing the running speed, the heart rate also became faster.

Basically, the result is logical due to the active muscle cell require more oxygen and energy delivered from blood which pumped from the heart during the increase of body movement. In other hand, the accuracy of heart rate by placing the pulse sensor on earlobe is much better than on finger. This phenomena may due to the sensor attach on earlobe has no significant muscle movement compare to finger. In addition, the ear has high temperature stability and no sweat.

The effectiveness of muscle activity detector was evaluated by EMG signal which is produced by the subject. The objective of this experiment is to investigate the relationship between the weight handled by the subject and the muscle signal produced [9]. Before the experiment, the EMG gel electrode is attached to the subject's bicep. During the experiment, the subject was indicated to work out of bicep curl with different set weight of dumbbell which were 5, 7.5 and 9.5 kg. The muscle signal received is recorded by using Coolterm software and is being tabulated. The time-domain graph is plotted from the data collected as shown in Figs. 9, 10 and 11. The experiment is repeated by using passive electrode. The burst moment is the muscle contraction moment which is easily noticed by the sudden break in the baseline, while silence moment is when no contraction is occurring, and therefore, the signal is maintained in baseline close to zero. This occurs due to the ups and downs of bicep curl workout where lifting the dumbbell form a higher EMG signal and release the dumbbell form a silence moment.

As mentioned earlier, the output signal of muscle sensor depends on the muscle contraction. The increase of muscle activation, the increase of output signal by muscle sensor was collected as shown in Fig. 12. Therefore, the 7.5 kg weight result a highest EMG signal due to larger strength is produced from the muscle while

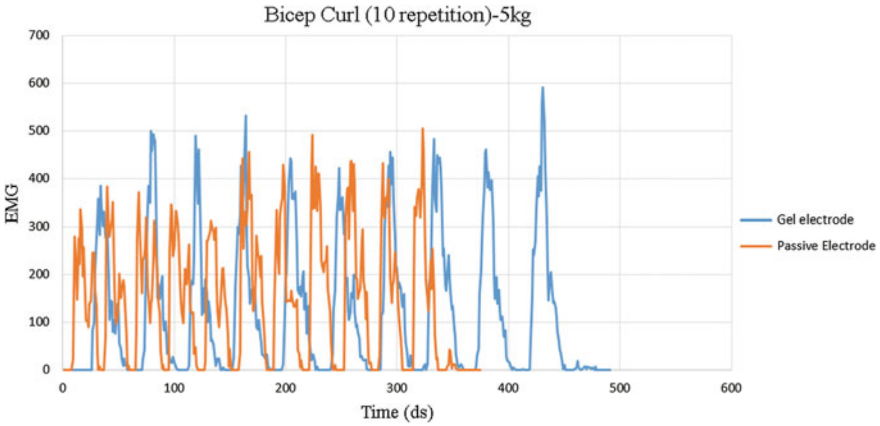


Fig. 9 Time domain when the dumbbell weight is 5 kg

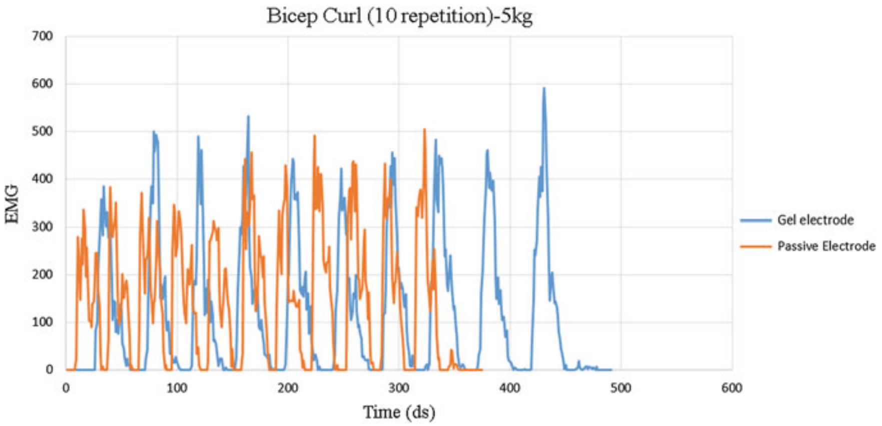


Fig. 10 Time domain when the dumbbell weight is 7.5 kg

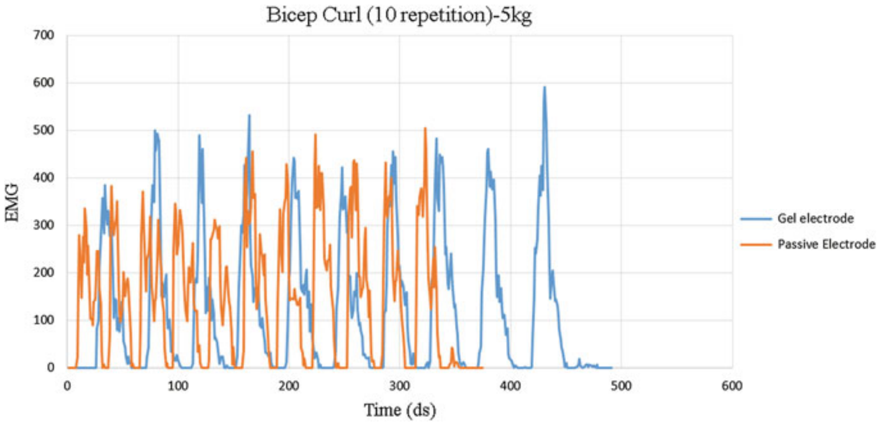
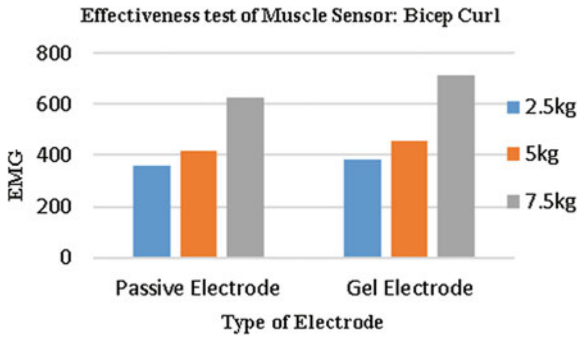


Fig. 11 Time domain when the dumbbell weight is 9.5 kg

Fig. 12 The effectiveness test of muscle sensor



taking control of the weight. The first experiment of 2.5 kg was result a similar waveform pattern; the second and third experiment of 5 and 7.5 kg, it was observed that EMG signal was getting increase; this is due to the muscle get tired and the bicep begin stressing and used more strength to lifting the dumbbell. As the weight of the work out getting increase, the strength also rises in order to accomplish the workout increase.

5 Conclusion

A continuous reading of heart rate and muscle activity is able to provide more realistic and accurate data to indicate athlete performance. With the completion of ECG and EMG system, several experiments have been conducted to ensure its reliability and stability. From the testing result, we can conclude that pulse sensor attach on earlobe to record the heartbeat due to high stability while using passive electrode to record EMG signal for long term used.

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References

1. Kranjec J, Beguš S, Geršak G, Drnovšek J (2014) Non-contact heart rate and heart rate variability measurements: a review. Biomed Signal Process Control 13(9):102–112
2. Türker H, Sözen H (ed) (2013) Surface electromyography in sports and exercise. In: Electrodiagnosis in new frontiers of clinical research, p 181
3. Xue S, Fei G, Lijuan H (2014) Different style of sports has different influence on the recovery of heart rate. J Am Coll Cardiol 64:74
4. Aleksandrowicz A, Leonhardt S (2007) Wireless and non-contact ecgmeasurement system—the “Aachen SmartChair”. Acta Polytech 47:68–71
5. Widhiasi A, Idrus R, Pasha MF, Syukur M (2013) A feasibility study scheme of an android-based integrated wearable ECG monitoring system. Procedia Comput Sci 21:407–414
6. Allen J (2007) Photoplethysmography and its application in clinical physiological measurement. Physiol Meas 28:1–39
7. Luca CJD (2002) The use of surface electromyography in biomechanics. J Appl Biomech 13:135–163
8. Han H, Kim J (2012) Artifacts in wearable photoplethysmographs during daily life motions and their reduction with least mean square based active noise cancellation method. Comput Biol Med 42(4):387–393
9. Tan SWCCW, Teo AWH, Lim WX, Goh DW (2014, 4/2/2015) Upper fitness personal assistant: body-guts. Available http://books.google.com.my/books?id=ca2gBAAAQBAJ&pg=PA59&lpg=PA59&dq=upper+fitness+personal+assistant:+body+guts+muscle+sensor+v3&source=bl&ots=_3vszKdfC6&sig=GpKpIbAm50mcaZcK_w9iHZDZRHs&hl=en&sa=X&ei=3HtgVPOMJtiJuATRvoD4BA&ved=0CB4Q6AEwAQ#v=onepage&q&f=false