Development of portable biofeedback devices for sport applications

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***Abstract*—The purpose of this project is to propose a portable low cost of ECG and EMG devices that plays the role of continuous monitoring of the user heart rate and muscle activity. Recording 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 determine 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 lab. Therefore, the development of this monitoring system capable provides immediate feedback about physiological data which is desired by athletes and trainers. The monitoring system is knitted with a pulse sensor and muscle sensor V3. Arduino Uno was act as microcontroller to analyze the collected signal then transmits the data via Bluetooth to Android based smartphone; Laptop through Processing software; or LCD screen. The significant of using Processing software is allow display the data in graphical way. The pulse sensor is applying photoplethsmography (PPG) technique to measure the heart rate in beats per minute (bpm). In other hand, the EMG signal will be collected by passive electrode which allows the monitoring of user muscle stress. Throughout the ECG experiment, 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. While the EMG data produced by muscle sensor is achieving a full wave rectified waveform that demonstrates the forearm strength produced.**

Keywords—Electrocardiography(ECG); Electromyography(EMG); Microcontroller; athlete.

I. INTRODUCTION

Basically, Electrocardiography (ECG) and Surface Electromyography (EMG) are non-invasive 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 live, both techniques have increasing important 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 improve the utilization of muscle and prevent risk of injury [2].

The conventional ECG and EMG tools were expensive and bulky. Therefore, the experiment was confined in hospital or biomechanical lab. Beside this, both measurement methods were using conductive electrodes which directly attached to the skin with 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 lead to certain needs for lower cost , user friendly and portable heart rate 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 capable transmit to Android base smartphone for further analyzing.

II. DEVICE DEVELOPMENT

Fig. 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 compatible for both pulse and muscle sensors to detect and measure the heartbeat and muscle activity respectively.

A. Electrocardiography (ECG)

For ECG system application, the pulse sensor was chosen which applied the photoplethysmography (PPG) technology to measure the heartbeat. Basically , PPG tools is an inexpensive and less power consume optical technique which measure the blood volume change in the vascular tissue [6]. The 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 reflectance mode where the photo-detector sensor and LED placing on the same side of 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 pulse sensor can attach on finger or earlobe.

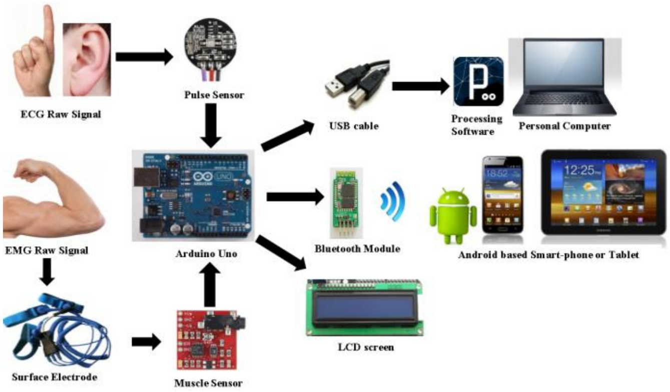

Fig. 1. An overview of the device system.

B. *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 circuit. The electrode measures the voltage difference which generate by muscle activation. The muscle sensor then amplifies, filtered and rectified the raw signal from human muscle and send to Arduino Uno. In the application of muscle sensor, the strength of muscle contraction is correspond to the amount of voltage output which mean the voltage output is depending on the amount of activation in the targeted muscle.

There are three platforms to display the collected data. Firstly, it can be display in Personal Computer (PC) via Processing programming interface. Second, with help of Bluetooth module, the data can send to Android based smart-phone wirelessly via Blueterm apps. Lastly, the data also can display in LCD directly after connect with the Arduino Uno.

The systems have considerable portability due to low weight and small size of component. Furthermore, the Arduino Uno is chosen as microcontroller due to it is a compact size device that has capability of high speed analog to digital conversion as well as low cost. For wireless technology of communication, the Bluetooth module was use in transmission of heartbeat and muscle activity data due to its low cost and small size. Meanwhile the Processing software was used to displaying the data from Arduino serial monitor in graphical way. There are about five main components in the development of 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.

III. EXPERIMENTAL DATA

After set 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 display by LCD screen is same with serial monitor of Arduino board. It displays both the digital value of pulse sensor and muscle sensor data as shown in Fig. 2. Next, Processing is an open source programming language which serves as visual context by graph the data from the microcontroller as shown in Fig. 3. Lastly, Bluetooth module is attached which act as bridge between the 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.

Fig. 2. LCD screen display heart rate and EMG.

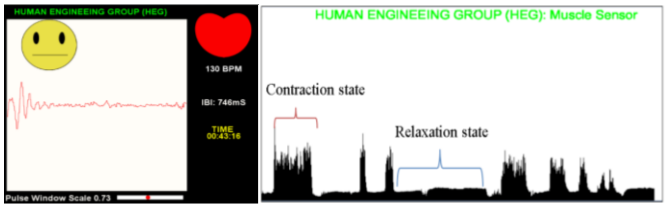

Fig. 3. Displaying heart rate (left) and muscle activation (right) via Processing programming interface.

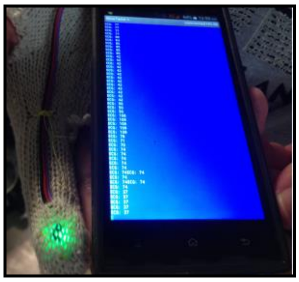

Fig. 4. Displaying ECG data on Android phone via Blueterm App.

A. *ECG validation process*

The pulse sensor can either attach in finger or 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 attach 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 were 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 stick on the surface of pulse sensor which is to prevent the sweaty or oil fingers which may affect the signal collection. In other hand, the second experiment is hot glue the pulse sensor on the ear clip for further measurement.

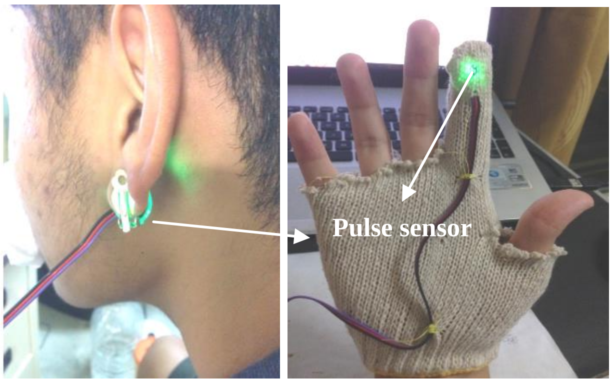

Fig. 5. Pulse sensor is clip on earlobe (left) and sew on glove (right).

B. EMG validation process

There are two type of electrode were using in this project which were gel surface electrode and passive electrode as shown in Fig. 5 and Fig. 6. The gel surface electrode is disposable electrode which mean the electrode have limited life time and cannot reuse. The advantage of this electrode is can conduct under body grounding or ungrounded condition. Fig. 5 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 placed 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].

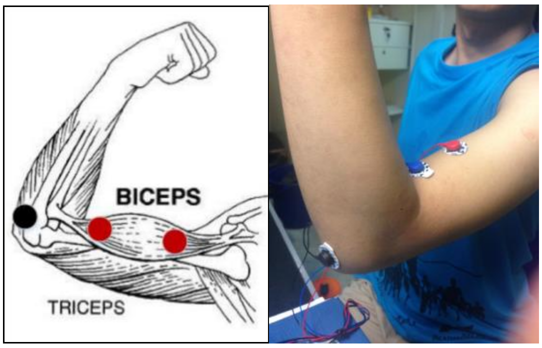

Fig. 6. EMG gel Electrode placement on bicep brachii.

In other hand, the passive electrode is the product of Olimex- EKG-EMG-PA. The advantage of the passive electrode is reusable after the measurement but it must make sure the body is grounded condition. It is means the result will affect if the subject leg is not in land. For the placement of passive electrode, The R snap connector is placed on the target muscle while L snap connector 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.

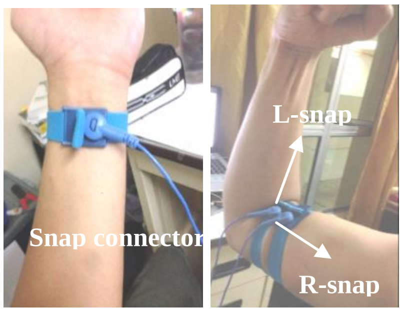

Fig. 7. Passive electrode placement on bicep brachii.

IV. RESULTS AND DISCUSSION

A pulse sensor's accuracy is evaluated by comparing the signal given by the sensor in finger and earlobe with manually counting the user's radial pulse [8]. 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 second, 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 Table I and Table II.

After the comparison of result Table I and Table II, it was shown that the accuracy of pulse sensor attach on earlobe and finger was only slightly difference or consider approximately same during the rest condition .

TABLE I. MEASUREMENT OF PULSE SENSOR ON FINGER AND RADIAL PULSE

Test	Pulse Sensor (BPM)	Radial Pulse (BPM)	Difference
1	76.73	75.00	1.73
2	72.00	70.00	2.00
3	70.75	67.00	3.75
4	70.00	68.00	2.00
5	82.43	81.00	1.43
6	77.42	78.00	0.58
7	80.82	80.00	0.82
8	85.87	87.00	1.13
9	85.70	86.00	0.30
10	85.07	84.00	1.07
		Average	1.48

TABLE II. MEASUREMENT OF PULSE SENSOR ON EARLOBE AND RADIAL PULSE

Test	Pulse Sensor (BPM)	Radial Pulse (BPM)	Difference
1	84.23	83.00	1.23
2	67.67	71.00	3.33
3	63.93	64.00	0.07
4	91.00	91.00	0.00
5	79.60	79.00	0.60
6	78.00	78.00	0.00
7	83.77	85.00	1.23
8	80.78	78.00	2.78
9	82.13	82.00	0.13
10	90.83	90.00	0.83
		Average	1.02

The second experiment involves physical activities by running of treadmill for the purpose of testing performance of heart rate monitoring system. The user was request to run on the treadmill with the speed of 8 km/hr for about three minutes. Then, the data start to record from pulse sensor on finger and treadmill respectively within 60 second. The procedure is repeated by attach the pulse sensor on user earlobe. The recorded results were shown in Table III.

TABLE III. HEART RATE DATA DURING THE TREADMILL RUNNING ACTIVITY

Placement of Pulse sensor	Pulse Sensor (BPM)	Treadmill (BPM)	Difference
Finger	125.67	113.56	12.11
Earlobe	125.61	120.19	5.42

The heart rate data of running in treadmill were higher compared to resting condition. 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 as shown in Table III. 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.

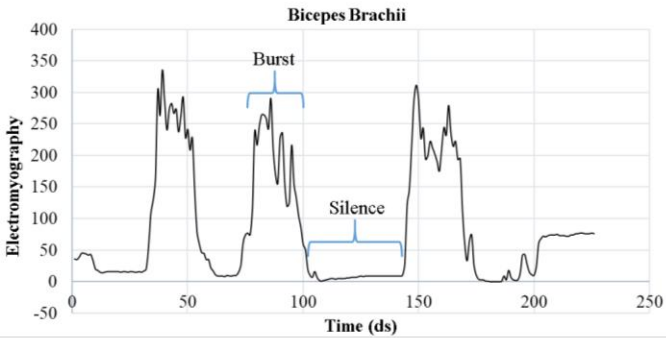

Fig. 8. EMG signal of bicep muscle with passive electrode.

In the experiment of muscle sensor, there are two type of electrode were using which are passive electrode and gel surface to record the EMG signal of user Bicep muscle. After finish the placement of passive electrode, the user were requested to make several time of muscle contraction and the EMG signal of user were recorded. The data were shown in Fig. 8 and Fig. 9.

As showed in Fig. 8, the Burst moment is the muscle contraction moment which easily noticed by the sudden break in the baseline Silence moment is when no contraction is occurring and therefore the signal stay maintain in baseline close to zero. As mention earlier, the output signal of muscle sensor is depending of the muscle contraction. The increase of muscle activation, the increase of output signal by muscle sensor was collected.

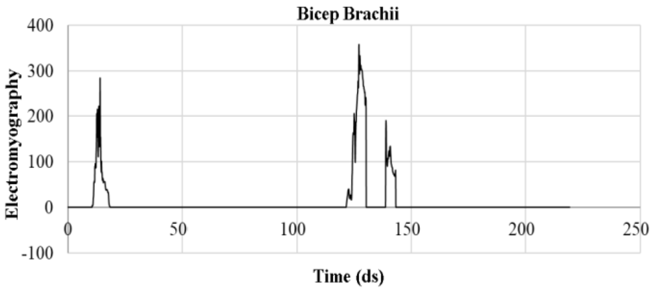

Fig. 9. First test of EMG signal of bicep muscle with gel electrode.

After the comparison of Fig. 8 and Fig. 9, the gel electrodes were produced good quality signal of EMG signal compared to passive electrode. Unfortunately, the gel electrode is disposable where the gel electrode will gain surface degradation after several tests and it may affect the data collection of EMG signal as shown in Fig. 10. However, the passive electrode is reusable and has no limit of life.

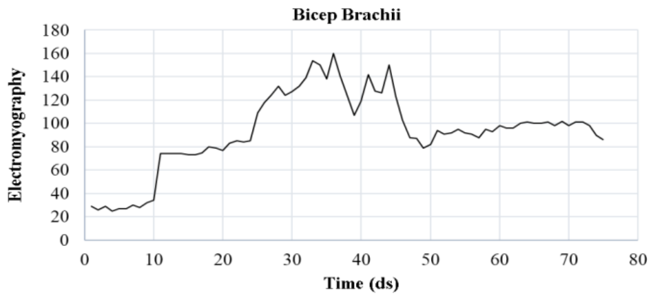

Fig. 10. Second test of EMG signal of bicep muscle with gel electrode.

V. RESULTS AND DISCUSSION

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 high stability while using passive electrode to record EMG signal for long term used. As a conclusion, the design of system can function as expected where user can assess and continue monitoring their physiological state.

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REFERENCES

[1] Kranjec J, Beguš S, Geršak G, Drnovšek J. Non-contact heart rate and heart rate variability measurements: A review. Biomedical Signal Processing and Control. 2014;13:102-12.
[2] Türker H, Sözen H. Surface Electromyography in Sports and Exercise. Electrodiagnosis in New Frontiers of Clinical Research2013. p. 181.
[3] Xue S, Fei G, Lijuan H. Different style of sports has different influence on the recovery of heart rate. Journal of the American College of Cardiology. 2014;64:74.
[4] Aleksandrowicz A, Leonhardt S. Wireless and Non-contact ECGMeasurement System – the "Aachen SmartChair". 2007;47:68-71.
[5] Widhiasi A, Idrus R, Pasha MF, Syukur M. A Feasibility Study Scheme of an Android-based Integrated Wearable ECG Monitoring System. Procedia Computer Science. 2013;21:407-14.
[6] Allen J. Photoplethysmography and its application in clinical physiological measurement. Physiological Measurement. 2007:1-39.
[7] Luca CJD. The use of surface electromyography in biomechanics. Journal of Applied Biomechanics. 2002;13:135-63.
[8] Tan CW, Chin SW, Teo AWH, Lim WX, Goh DW. Upper Fitness Personal Assistant:Body-Guts. International Colloquium in Textile Engineering, Fashion, Apparrel and Design 20142014.