The investigation of joint angle movement using bio-impedance

RenHe, Liu

A Thesis Submitted in Fulfillment of the Requirements for the Degree of

Master of Engineering in Electrical Engineering

Prince of Songkla University

2016

The Investigation of Joint Angle Movement Using Bio-Impedance

RenHe Liu

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Electrical Engineering

Prince of Songkla University

2017

Thesis Title The Investigation of Joint Angle Movement using Bio-impedance Signal

Author Mr. Liu RenHe

Major Program Electrical Engineering

Major Advisor

....
(Assoc. Prof. Booncharoen Wongkittisuksa)

Examining Committee :

......................................Chairperson
(Assoc. Prof. Dr. Pornchai Phukpattaranont)

....Committee
(Assoc. Prof. Booncharoen Wongkittisuksa)

....Committee
(Dr. Kittikhun Thongpull)

....Committee
(Asst.Prof.Dr. AjalawitChantaveerod)

The Graduate School, Prince of Songkla University, has approved this thesis as partial fulfillment of the requirements for the Master of Engineering Degree in Electrical Engineering

....
(Assoc. Prof. Dr. Teerapol Srichana)
Dean of Graduate School

This is to certify that the work here submitted is the result of the candidate's own investigations. Due acknowledgement has been made of any assistance received.

……………………………………...Signature
(Assoc. Prof. Booncharoen Wongkittisuksa)
Major Advisor

....Signature
(Mr. Liu RenHe)
Candidate

I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

....Signature
(Mr. Liu RenHe)
Candidate

Thesis Title The Investigation of Joint Angle Movement using Bio-impedance Signal

Author Mr. RenHe Liu

Major Program Electrical Engineering

Academic Year 2016

Abstract

Electromyography (EMG) method is widely used in motion detection based on physiological phenomenon. However, EMG technique doesn't fit to measure the dynamic parameter of motion. For instance, EMG is difficult to measure the joint angle changing. Bio-impedance method is a non-invasive, high performance method. This article evaluates the elbow joint movement using Bio-impedance, the correlation between the elbow joint angle changing and the upper arm bio-impedance changing has been calculated. A one-channel Bio-impedance measurement device with a goniometer has been designed in this study. The bio-impedance device generates high-frequency, low-intensity alternating constant current to human body and measure the bio-impedance signal. 20-kHz, 45-kHz, 50-kHz and 70-kHz has been investigated in the experiment. The one-channel bio-impedance measurement device includes of Wein oscillator, Howland constant current source, high-pass filter, the instrument amplifier INA 128, rectifier, low-pass filter and direct current coupling. Three electrode configurations were applied to compare the influence from each electrode configuration to the correlation calculation. Four male and two female have participated in the experiment of 70-kHz with three electrode configuration. In the experiment of 20-kHz, 45-Khz and 50-kHz, only one subject has participated in these experiments. The motion setting of 45-kHz is different with other frequency condition, it consists of 9 stages. Subject lifted their arms from 0 degrees to 80 degrees and kept their arm at each 10 degrees. The other motion setting consists of 4 stages. Subject lifted their arms from 0 degrees to 90 degrees and kept their arm at each 30 degrees. In multi-frequency with different electrode configurations condition, the result of 45-kHz, 50-kHz and 70-kHz contribute high correlation between the elbow joint angle changing and upper arm bio-impedance changing. However, the result of the 20-kHz condition is not stable. In the multi-subject experiment, each subject contributes high correlation result in the 70-kHz condition with three electrode configurations. The last part of Thesis shows the statistical analysis using paired T-test method to observe the influence from different parameter to the correlation between elbow joint motion and bio-impedance changing. The result of paired T-test method shows different electrode configurations have different influence on the bio-impedance measurement.

Keyword: the evaluation of elbow joint motion, statistical analysis, one channel system, three electrode configurations, multi-frequency bio-impedance analysis

บทคัดย่อ

ชื่อวิทยานิพนธ์ The Investigation of Joint Angle Movement using Bio-impedance Signal

ผู้เขียน Mr. RenHe Liu

สาขาวิชา วิศวกรรมไฟฟ้า

ปีการศึกษา 2559

บทคัดย่อ

งานวิจัยนี้เป็นการศึกษาการเคลื่อนที่ของข้อศอกโดยใช้หลักการวิเคราะห์การเปลี่ยนแปลงค่าของไบโออิมพีแดนซ์เปรียบเทียบกับการเปลี่ยนแปลงของมุมของข้อศอกโดยใช้วิธีการวัดแบบ 1 ช่องสัญญาณ ซึ่งเป็นการใช้อิเล็กโตรด 3 ตัว เพื่อหาความสัมพันธ์ระหว่างองศาในการเคลื่อนที่ของแขนท่อนบนกับค่าการเปลี่ยนแปลงของค่าไบโออิมพีแดนซ์ร่วมกับเครื่องวัดมุม งานวิจัยนี้ได้ทำการออกแบบเครื่องมือให้เป็นแบบความถี่สูงและใช้กระแสต่ำ การวัดจะถูกทำที่ความถี่ 20 45 50 และ 70 เฮิรตซ์ โดยกำหนดท่าทางการเคลื่อนไหวเป็น 2 ลักษณะ การเคลื่อนที่แบบแรกเป็นกำหนดการเคลื่อนที่ของแขนเป็น 9 ช่วง โดยเริ่มจาก 0 องศา เคลื่อนที่ไปจนถึง 90 องศา โดยกำหนดเป็นช่วง ช่วงละ 10 องศา และการเคลื่อนไหวในลักษณะที่สองเป็นการกำหนดการเคลื่อนที่ของแขนเป็นแบบ 4 ช่วง โดยเริ่มจาก 0 องศา ไปจนถึง 90 องศา โดยกำหนดให้ช่วงการเคลื่อนที่แต่ครั้งเป็น 30 องศา การศึกษาในงานวิจัยนี้เป็นการใช้การวัดแบบ 1 ช่องสัญญาณ ซึ่งถึงออกแบบให้มีวงจรต่างๆ คือ วงจรสร้างความถี่ วงจรสร้างกระแสคงที วงจรกรองความถี่สูง วงจรกรองความถี่ต่ำ วงจรเชื่อมต่อสัญญาณ และ วงจรขยาย การวิจัยนี้ทำการศึกษาการวางอิเล็กโตรด สามตำแหน่ง เพื่อทำการคำนวณหาค่าความสัมพันธ์ระหว่างการเปลี่ยนแปลงของ ไบโออิมพีแดนซ์ กลุ่มตัวอย่างที่ใช้ในการทดลองมีทั้งหมด 6 คน แบ่งเป็น ผู้ชาย 4 คน และผู้หญิง 2 คน จากการทดลองเบื้องต้นพบว่า ความถี่ที่เหมาะสมสำหรับกลุ่มการทดลองนี้คือ คือ ความถี่ที่ 70 เฮิรตซ์ ซึ่งเป็นช่วงความถี่ที่สามารถวิเคราะห์ค่าความสัมพันธ์ระหว่าง การเปลี่ยนแปลงของไบโออิมพีแดนซ์เปรียบเทียบกับการเคลื่อนที่ในแต่ละช่วง เมื่อเปรียบเทียบกับความถี่ที่ 45 และ 50 เฮิรตซ์ จากการวิเคราะห์ในความถี่ที่ 20 เฮิรตซ์ พบว่าการเปลี่ยนแปลงไม่เสถียร จึงไม่สามารถนำมาวิเคราะห์ได้ เมื่อวิเคราะห์ถึงความสัมพันธ์ของการเปลี่ยนแปลงของ ไบโออิมพีแดนซ์และการเคลื่อนที่ของแขนแล้ว ผลการทดลองได้ถูกนำไปวิเคราะห์โดยวิธีทางสถิติเพื่อทำการวิเคราะห์ว่า มีปัจจัยอื่นที่ส่งผลต่อการทดลองรวมถึงตำแหน่งที่การติดตั้งอิเล็กโตรด ส่งผลต่อผลการทดลองหรือไม่ ซึ่งจากผลการวิเคราะห์โดยวิธี pair sample T-Test พบว่า ตำแหน่งที่ติดอิเล็กโตรด มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ

คำสำคัญ : การวัดค่าไบโออิมพีแดนซ์แบบ 1 ช่องสัญญาณ : การศึกษาเคลื่อนที่ของข้อศอกด้วยไบโออิมพีแดนซ์: ความสัมพันธ์ระหว่างการเคลื่อนที่ของข้อศอกกับการเปลี่ยนแปลงของค่าไบโออิมพีแดนซ์

Content

List of Tables

List of Figures

Chapter 1
Introduction

1.1 Background and problem statement

Accident and some disease cause a lot of arm disability, even death, moreover, with terrorism become a worldwide problem. More and more soldiers and civilians become disabled and even lose their lives. Statistical data shows that the population of arm amputees of the worldwide increase to 3 million, this number is 30% of the world population of amputees at 2008 [1].

This study proposes an algorithm of joint angle movement using bio-impedance changes to an application. Bio-impedance method is a non-invasive, painless approach. This approach also can evaluate the assessment of muscle rely on measurement of high-frequency, low current [2]. Bio-impedance approach compare with the Electromyography (EMG) approach, bio-impedance approach is not concentrating on some of intrinsic activity of human muscle and tissues. But bio-impedance approach are interested some area, these area are some tissue where being injected high-frequency and also low constant current. When the area of arm surface tissue were applied electrical constant current have motion, for instance, arm flexion or extension, which will cause bio-impedance of the area have changed, moreover, the signal of bio-impedance is relatively pure.

The conventional methods for measurement of physical exercise in nowadays. For instance, the goniometer technology, EMG approach, the camera and the video camera. Each technique have their own advantage and disadvantages. The first method, the goniometer technology not suit for patient to training with complex or quick rehabilitation. It is due to the physical structure of the technique [3] [4]. The second method, using EMG technique to evaluate the patient movement not have kinematic parameter and dynamic parameter [3] [4]. The third method, the camera technique needs quite much time to process the data [3] [4]. The fourth method, the video technique is limited by space, and it needs high cost and complex handle [3] [4]. The video technique not convenient for user due to involving user privacy.

The advantage of bio-impedance technique as following. The first, bio-impedance technique not concern for the problem of space for measurement. The result of bio-impedance is quite easy to understand and unnecessary much procedure, and it can be compressed and measured continuously during enough period. Single joint bio-impedance signal can combined with more application due to its simple signal processing. This advantage is suitable for this area of technology has developed rapidly.

Nowadays, there also have lot of arm control technology. For instance, some researchers use EMG signal, Electroencephalogram (EEG) signal or Electrooculography (EOG) signal to control application. EEG signal although can make the earliest predictions about the intended reach target, however, EEG signal may be affected by motion artifacts, and EEG technology have low accuracy after motion onset. EOG signal have the same problem as EEG approach after motion onset [5]. EMG signal have good accuracy after motion onset. However, EMG signal has the intrinsic property, EMG technology hardly have immediate action when devices received the signal, because most of the EMG technology using threshold control [6].

When bio-impedance technology compare with EEG technology or EOG technology, it has good accuracy after motion onset0. When there compares bio-impedance with EMG technology. Bio-impedance technology also can evaluates motion immediately, since when the tissue of arm stretch or constriction, bio-impedance of the arm will change immediately [7]. Moreover, Bio-impedance is suitable to evaluate the motion of the joint angle of the limb over a long time.

As the reported [2], we can find the frequency of bio-impedance signal is relatively wide when we compare bio-impedance signal with EEG, EOG signal. Bio-impedance signal frequency range from 20 to 100 KHz, which can in case interfere the signal from the human body. The other method compares with the current source frequency for bio-impedance signal detection has unusual narrow bandwidth. The frequency response range of EOG is from 0.2 to 3.0Hz. The range of EMG and EEG are 70-1000Hz and 0.5- 45Hz, respectively [8]. The wide frequency response range of bio-impedance make easier measurement than others approach.

There also have some research shows that the range of the EMG signal amplitude by voluntary contraction is 0-10 mV p-p [9], furthermore, the device and system of bio-impedance for measurement or control robot arm is quite easy to be mastered and cheaper.

The Bio-impedance approach also have possessed some limitation. When we collect the bio-impedance signal from upper limbs, for instance, which including chest, pelvis, thigh, calf or arm will be influenced by cardiac output. Nevertheless, the magnitude of the noise of heartbeat effect is not significant, and it is also having the same pattern of noise signal. If we adjust the value of threshold, the negative effect from heartbeat can be reduced by signal processing [10]. The second limitation of bio-impedance is about multi-joint angle movement measurement. The system of bio-impedance is difficult to recognize the signal from multi-joint angle movement and it requires calibration to measure accurate joint angles in each subjects [7]. This thesis aims to investigate the relationship between bio-impedance changes and the joint angle changes. This thesis measure the bio-impedance using different electrode configuration to find the optimal electrode configuration. When joint angle of elbow change, the muscle and tissues volume also change, it causes bio-impedance of upper arm change.

1.2 Objective

1.2.1 To find the correlation between bio-impedance signal and elbow joint angle changing.
1.2.2 To evaluate elbow joint motion using multi frequency bio-impedance signal and three electrode configurations.
1.2.3 To evaluate the elbow joint motion using three electrode configurations with 6 subjects.
1.2.4 To validate the effect on the measurement of bio-impedance from three electrode configurations using statistical analysis.

1.3 Research scope

1.3.1 Measure the bio-impedance from health human.
1.3.2 Find the relationship between the changing of bio-impedance and joint angle movement and set five point of joint angle for bio-impedance changing.
1.3.3 Develop a simulation using the relationship between the changing of bio-impedance and joint angle movement.

1.4. Research plan

1.4.1 Study the method to measure bio-impedance on a human arm.
1.4.2 Find the relationship between the changing of bio-impedance and elbow joint angle movement.
1.4.3 Using the relationship to an application for amputees to do some rehabilitation exercise.
1.4.4 System verification and validation.
1.4.5 Conclusion and report.

Chapter 2
Literature review

2.1 Fundamental of bio-impedance measurement techniques

Bio-impedance is the ability of the body to impede the Alternating current flow, it is dependent on the frequency of the injected current flow and it composed of magnitude $|Z|$ and phase angle $\emptyset$ as equations(1)-(3)[4].

$$Z = R + jX_C \tag{1}$$

$$|Z| = \sqrt{R^2 + X_C^2} \tag{2}$$

$$\phi = \tan^{-1}(\frac{X_C}{R}) \tag{3}$$

The quantity of bio-impedance consists of resistance(R) and reactance X_C. Resistance is caused by total body water, reactance is caused by cell membrane [1], the length(L), surface area(A) and the resistivityρ, will influence resistance as equation (4)[4].

$$R(ohm) = \rho(\Omega, m)\frac{L(m)}{A(m^2)} \tag{4}$$

Different type of material has different resistivity ρ, it is dependent on frequency. Reactance X_C is caused by the capacitance of cell membrane [5]. It is influenced by frequency of injected current and the capacitance of cell membrane as equation (5). [1, 5] Capacitance (C) is considered as the ability of the non-conducting object to save electrical charges, which is equal to the ratio between differentiation in voltage across object (dV/dt) and current that is passed through (I(t)), it is described as equation (6). In the parallel capacitor module, surface area (A) in meters square and distance (d) in meters between the charged plates has effect on the capacitance, surface area (A) is proportional to the capacitance and distance (d) is inversely proportional to the capacitance. Permittivity constant of vacuum (ε_0) and relative dielectric permittivity constant (ε_γ) have relationship with the capacitance, both of them are dependent on the frequency of injected current, as shown in equation(7).

$$X_C(ohm) = \frac{1}{2\pi f(Hz)C(Farad)} \tag{5}$$

$$I(t) = \frac{dV}{dt} / C(farad) \tag{6}$$

$$C(farad) = \varepsilon_0 \varepsilon_r \frac{A(m^3)}{d(m)} \tag{7}$$

As the equation (4), length (L) and material type are proportional to resistance, surface area (A) is inversely proportional to resistance. Moreover, there has the other research showed that the volume (V) is a significant value to estimate body construct using bio-impedance method [11]. Thus, the equation (4) was transferred to equation (8) through volume (V).

$$V(m^3) = \rho_{(\Omega.m)} \frac{L^2_{(m)}}{R_{(ohm)}} \tag{8}$$

The volume is represent to the human body. According to equation (8), volume (V) has relationship with bio-impedance. It is due to the weight of human whole body is mainly composed of fat mass (FM) and fat free mass (FFM) as shown in equation (9). FM is considered as non-conductor of electric charge. FFM is considered as conductor, which caused by electrolytes dissolved in body water and cell mass. Some research shows that total body water (TBW) is the main component of FFM as equation (10) [12], TBW is almost equal to 73.2% of FFM as previous works. [1 2 3 4]

$$Wt_{body} = FM + FFM \tag{9}$$

$$TBW = 0.73FFM \tag{10}$$

Due to the human body is not homogeneous volume. Thus, some previous researcher separate it into five segment for the bio-impedance method, Fig. 1 shows this concept. In this concept, total body weight consists of FM and FFM which consists of bone minerals and body cell mass (BCM). BCM has resistance and capacitance in bio-impedance measurement. It is due to BCM consists of protein and TBW which includes of extracellular fluid (ECF) and intracellular fluid (ICF) [5]. Resistance is composed by the function of ECF and ICF for impedance bio-measurement. Capacitance is composed by the function of cell membrane in Bio-impedance measurement, which divide ECF and ICF.

Body segment is a homogeneous component and consists of resistance and reactance as shown in previous works. Thus, body segment has different response when there has different frequency of injected electric current. Some previous research analysis bio-impedance using single frequency, multiple frequencies or bio-impedance spectroscopy analysis [2, 12, 13]. Moreover, there has several alternative assessments methods which is mentioned in review [13].

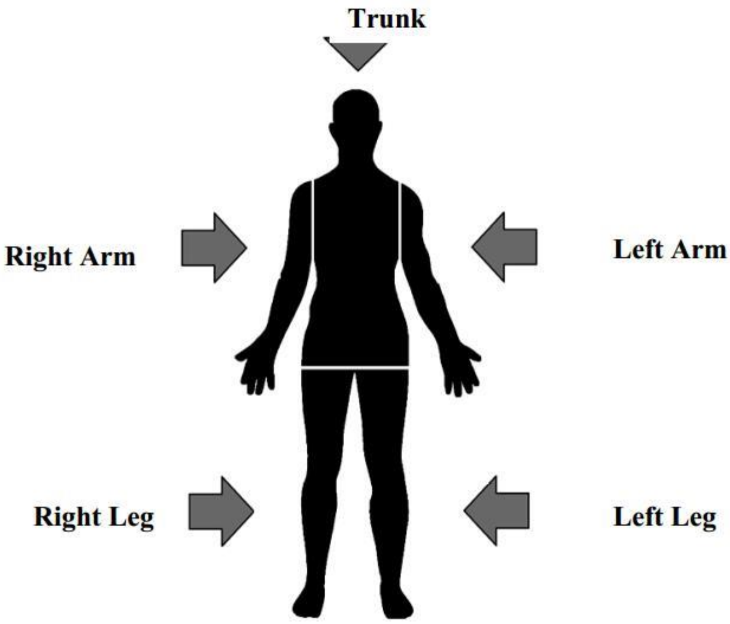


Fig. 1 Main body segments and compartments [13]

2.2 Single frequency bio-impedance analysis (SF-BIA)

According to the most of previous research, 50-kHz electric current flow is commonly used in bio-impedance measurement [2, 12, 13]. SF-BIA is one of the earliest method for evaluation of body components. It depend on the inverse proportional relationship between impedance and TBW, which is correspond to the conductive path of the electric current [12, 14]. SF predicts the volume of TBW, which obtain ECF and ICF [12, 13]. However, there has the other research shows 50-kHz BIA is strictly speaking not measuring TBW but an evaluation of the resistivity of ECF and ICF [12]. Despite of SF-BIA is not certain for the state with altered hydration, it is useful for the evaluation of fat free mass

(FFM) and TBW [15]. However, SF-BIA is not useful for the measurement of ICF differences [16].

2.3 Multiple frequency bio-impedance analysis (MF-BIA)

MF-BIA evaluate body component (FFM, TBW, ICF and ECF) using different frequencies (0-500 kHz). Some earliest researcher predict TBW and ECF through 100 and 1 kHz, it accord to the rule of Cole model [13, 17]. After later years, there has other researcher shown the frequency of injected electric current should at 5-1000 kHz [18]. At low frequency or high frequency, it mean the frequency is lower than 5-kHz or higher than 200-kHz, there has poor reproducibility [19]. MF-BIA is fitter to evaluate ECF than SF-BIA method. However, SF-BIA is fitter and less bias for measurement of TBW in unhealthy subjects [12].

2.4 Bioelectrical spectroscopy (BIS)

BIS applies mathematical modeling and mixture equations (e.g. Cole-Cole plot (fig.2) and Hanai formula) [12] to predict the ECF and TBW using the relationships between R_0 which is the resistance response at lowest frequency and R_∞ which is the resistance response at highest frequency. The relationship between R_0 and R_∞ develop predicting equations rather than go to mixture modeling [20]. However, the constants and equations were generated from BIS model, which were accurate for healthy subjects, thus, this modeling method need more different disease subjects in future. Some previous research shown body cell mass (BCM) is the main path for current flow, especially muscle mass. They consider the cells shape not as non-spherical, but like cylindrical [21]. Moreover, it is hard to certify the values of resistivity, it is due to previous research were very different [12].

Mixture equations could make the result better in some case of study [22, 23, 24]. However, mixture equations were caused no helpful result [25, 26] or worse result than regression method in other case of study [27]. BIS method has high potential and it need more accurate data to improve itself.

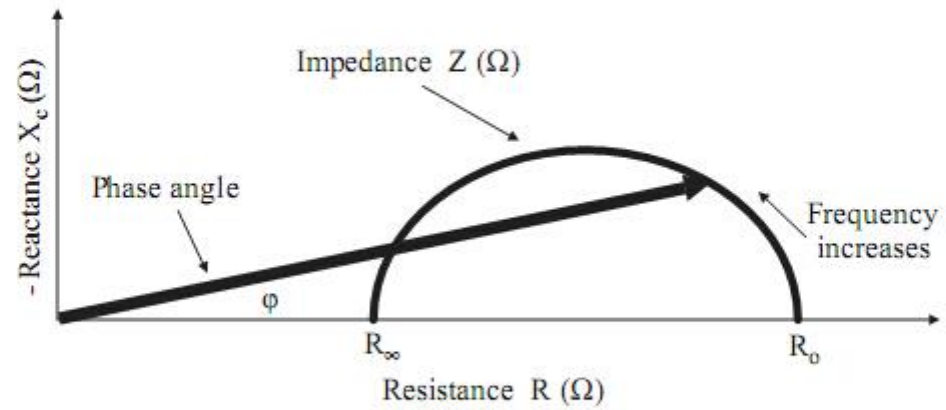


Fig. 2 Diagram of the graphical derivation of the phase angle; its relationship with resistance (R), reactance (Xc), impedance (Z) and the frequency of the applied current [12]

2.5 Whole body bio-impedance measurement

According to previous research, the most of whole body bio-impedance measurement apply three methods: hand to foot method [15, 28], foot to foot method [29, 30, 31] and hand to hand method [32, 33]. The hand to foot method is the most commonly used method [13]. In the previous paper for the hand to foot method, tetrapolar hand to foot measurement is used in a supine subject for 15 min, the electrode placed on the dorsal surfaces of the right hand and foot, distal ones being respectively proximal to the metacarpal and metatarsal phalangeal joints. It accord to the standard tetrapolar electrode configuration [34]. A pressure contact food-pad electrode was applied in the foot to foot method for whole body bio-impedance measurement. Four stainless steel footpads electrodes were applied in the leg to leg method, these four footpads separates each foot into frontal and back portion, two of them were used to inject current to human body, two of them were used to measure voltage. Some previous thesis measure bio-impedance from the subject who has malnutrition condition [33]. They uses hand to hand method to analysis the body component of subjects using handheld impedance meter. The other researcher validate its result for hand to hand method and show the hand to hand method is acceptable [32].

2.6 Body segment bio-impedance measurement

Compare with whole body bio-impedance measurement, segment bio-impedance analysis has more accuracy for prediction of skeletal muscle mass (SMM) [35], moreover, it give better prediction of TBW than total body bio-impedance analysis with dilution method [36]. Multi-frequency segmental bio-impedance analysis improve the relationship between body component and bio-impedance method [37]. Segmental bio-impedance analysis predict the difference in ECF and is more accurate than the ankle foot method [38].

There has four types of segmental bio-impedance tools. The first one of them uses two electrodes which placed on right forearm and lower leg for current injection, four voltage electrodes were placed on right proximal forearm, shoulder, upper thigh and lower leg [13] as Fig. 3 (a). Fig. 3 (a-d) is from the reference [13]. The second of them uses two electrodes which placed on the right wrist foot for current injection, four voltage electrodes were placed on the right wrist, shoulder, upper iliac spine and foot [13] as Fig. 3 (b). The third of them uses two electrodes which placed on the right wrist and foot for current injection, four voltage electrodes were placed on right and left wrist and foot [13] as Fig.3 (c). The fourth of them uses four electrodes which placed on the right and left wrist and foot for current injection, four voltage electrodes were placed on the same position [13] as Fig. 3 (d).

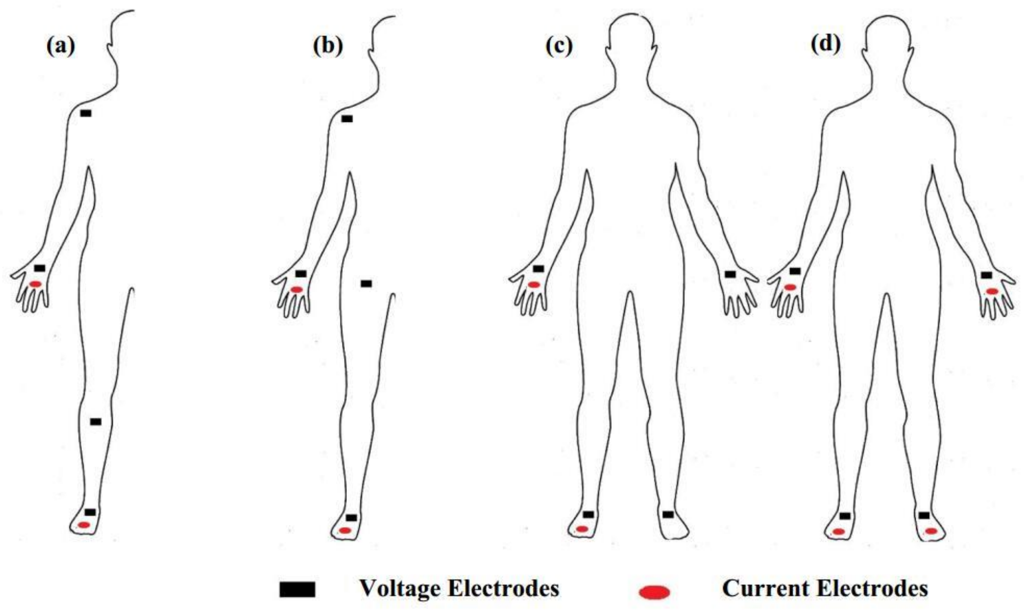


Fig. 3 Segmental bioimpedance analysis techniques, (a) right side dual current and quad voltage electrodes, (b) right side dual current and quad voltage electrodes, (c) double sides dual current and quad voltage electrodes and (**d**) double sides quad current and quad voltage electrodes[13]

Some previous show segmental bio-impedance analysis can predict abdominals fat with a high correlation coefficient$R^2 = 0.99$; moreover, the limitation of segmental bio-impedance analysis is about the prediction of FFM [39].

2.7 Body component estimation using bio-impedance analysis

FFM is the weight of body except for body fat mass. FM and FFM are significant value of the body composition assessment techniques. There has too many equations to estimate FFM from previous research. The most of them vary the parameter which included in the multiple regression equations. The early BIA equation only mention $Height^2/resistance$. There has more parameter added into the equation with the development of BIA technology, for instance, weight, age, gender, reactance and anthropometric measurements of the trunk or extremities. SF-BIA can predict FFM as shown from chapter 4.11. There has some previous equation (11) for prediction of FFM: Kyle *et al.* [40] made a FFM equation reference to DXA method:

$$\text{FFM} = -4.104 + 0.518\text{ht}^2 / R_{50} + 0.231wt + 0.130X_{c,50} + 4.229sex$$
$$\text{sex} = 1, \text{ male or } 0, \text{ female} \tag{11}$$

Where ht is body weight, $R_{50}$and $X_{c,50}$ is resistance and reactance at 50-kHz, wt is body weight. This equation achieved a correlation coefficient (R) is equal to 0.986, standard error of the estimate (SEE) is equal to 1.72 kg and technical error is 1.74 kg. Sun *et al.* [41] made the equation of FFM using multi-component model based on densitometry, isotope dilution and dual-energy X-ray absorptiometry as equation (12) and (13).

$$\text{FFM}_{male} = -10.68 + 0.68ht^2 / R_{50} + 0.26wt + 0.02R_{50} \tag{12}$$
$$\text{FFM}_{femail} = -9.53 + 0.69ht^2 / R_{50} + 0.17wt + 0.02R_{50} \tag{13}$$

The mean FFM prediction achieved correlation coefficientR^2=0.90 and 0.83, the root mean square errors of 3.9 and 2.9 kg for males and females, respectively. A previous paper show the progress of development of FFM equation [13].

2.8 Body fluids

The most volume of FFM is Body fluid. The previous research call the water of whole body as total body water (TBW). When there has high frequency current injected into body segment, the current will flow from the extracellular fluid/water (ECF/ECW) which is in the outside of cell to the intracellular fluid/ water (ICF/ICW) which is in the inside of cell. TBW is composed by ICF and ECF. The Fig. 4 shows the relationship between body fluid and other body component.

Fig. 4 The relationship between body fluid and other body component, whole body weight is composed by fat mass and fat free mass which is consists of bone mineral, protein and total body water.

2.9 Whole-body impedance-what does it measure? [11]

This study introduces the equation of bio-impedance measurement. Bio-impedance measured by injecting a suitable frequency alternating current into body segment and using electrode to measure the voltage of each body segment where injected current as we known. Bio-impedance include resistance and reactance (capacitance). This research combines capacitance and resistance in two ways: in series or in parallel, moreover, this research introduces the equation of different bio-impedance in series or in parallel ways.

Series-equivalent circuit

Series-equivalent model demonstrate in the Fig. 5 composed by a resistor R_S in series with a capacitor C_S. The magnitude of the impedance in the series equivalent circuit can be expressed by the equation (14):

$$Z = \sqrt{R_s^2 + \frac{1}{(2\pi fC_s)^2}} \tag{14}$$

And the phase θ between resistance and reactance as the equation (15):

$$\theta = -\arctan(\frac{1}{2\pi fR_sC_s}) \tag{15}$$

Where f is the frequency; R_S is resistor of the series equivalent circuit; C_S is capacitor of the series equivalent circuit. In this study. Equation (16) expresses the series equivalent circuit in term of a quantity:

$$Z^* = R_s - \frac{j}{2\pi fC_s} = R_s + jX \tag{16}$$

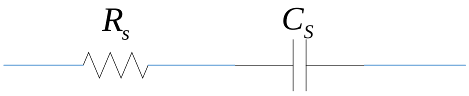


Fig. 5 Series-equivalent circuit

Parallel-equivalent circuit

The parallel-equivalent circuit consists of a resistor R_p parallel with a capacitor C_p) as shown in Fig. 6 The series-equivalent impedance of this circuit can got by some parameter of the parallel circuit. The series-equivalent resistance R_S and reactance R_x can be express as equation (17) and (18)

$$R_s = \frac{R_p}{1+(2\pi fC_pR_p)^2} \tag{17}$$

$$X = \frac{-2\pi fC_pR_p^2}{1+(2\pi fC_pR_p)^2} \tag{18}$$

The magnitude of this equivalent circuit as equation (19)

$$Z=[\frac{1}{\frac{1}{R_p^2}+(2\pi fC_s)^2}]^{\frac{1}{2}} \tag{19}$$

The phase between R and X of this circuit is equation (20)

$$\theta=-\arctan(2\pi fC_pR_p) \tag{20}$$

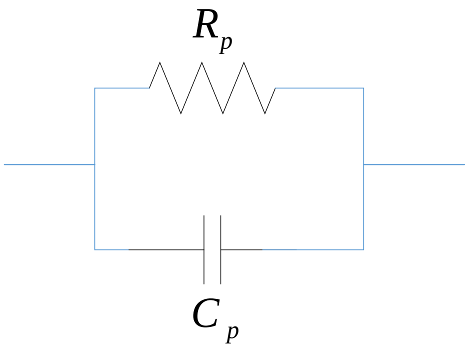


Fig. 6 Parallel-equivalent circuit

Whatever the researchers prefer to understands bio-impedance equivalent circuit as series-equivalent circuit (R_s and C_s) or parallel-equivalent circuit ($R_p$and C_p) is depends on the researchers' convenience.

This research also shows a number of properties. For instance, intensive and extensive electrical properties. Some properties of body tissues, which like bio-impedance or height depends on body size. This research calls those properties as extensive properties. Body tissues also have a number of inherent properties, which is expressed as intensive properties. Two intensive electrical properties are introduced in this study. They are conductivity (σ) and permittivity (ε'). When body tissues injected AC current, the measurement of the amount of electrical current flow in electrical field of body tissues can be explained as conductivity. Resistivity (ρ) be regarded as$\Omega \cdot$ m, which is regarded as the inverse of conductivity. Resistivity also can be defined to parallel-circuit model. Due to cell membrane is regarded as a capacitor. Body tissues also have capacitive character when injects current flow to it. Permittivity is the definition of the amount of charge when injects current flow to body tissues. Permittivity also can be defined to parallel circuit. This study shows some equation of conductivity and permittivity as equation (21) and (22):

$$C_p = \varepsilon' \varepsilon_0 \frac{A}{L} \tag{21}$$

$$R_p = \rho \frac{L}{A} \tag{22}$$

Where ε_0 is the permittivity of free space, it is regarded as a constant number. ε' is relative permittivity. They are using A and L instead of the cross sectional area and length of the conducting materials. Conductivity and permittivity are defined into part of the parallel-equivalent circuit. It due to these two electrical properties is happening independently. Conductivity and permittivity also can be used to instead of capacitance C_p and resistanceR_p in equation (23) and (24).

$$R_s = \frac{L}{A}[\frac{\rho}{1+(2\pi f \varepsilon_0 \varepsilon' \rho)^2}] \approx \frac{L}{A}\rho \tag{23}$$

$$X = \frac{-L}{A}[\frac{2\pi f \varepsilon' \varepsilon_0 \rho^2}{1+(2\pi f \varepsilon_0 \varepsilon' \rho)^2}] \approx \frac{-L}{A}[2\pi f \varepsilon' \varepsilon_0 \rho^2] \tag{24}$$

However, $2\pi f \varepsilon_0 \varepsilon' \rho$ is much less than 1, thus, the study ignores it in the equation. Moreover, conductivity and permittivity are frequency dependence. Therefore, frequency is the key of bio-impedance measurement. Most of the bio-impedance measurement research using single -frequency bio-impedance analysis at 50-KHz.

2.10 Bioelectrical impedance analysis--part I: review of principles and methods [12]

The length of even conductive material of uniform cross-sectional area is proportional to its resistance(R). However, its cross-sectional area is inversely proportional to its resistance(R). Despite human body not a homogeneous cylinder, moreover, the conductivity of the human body is not a constant value. A4n empirical relationship between impedance quotient (Length²/R) and the volume of water come under observation. In practice, it is easier to measure height than the length of material in human body. Due to the intrinsic property of human body, impedance quotient (Length²/R or Height²/R) equivalent to cylinder. Therefore, when the ratio of the length of conductive material to the height of conductive material isn't appropriate, or variations in the shape of human body segment, error of measurement as equation (25).

$$R = \rho L^2 / V \tag{25}$$

Fig. 7 shows the schematic of body segment and four-channel bio-impedance measurement system

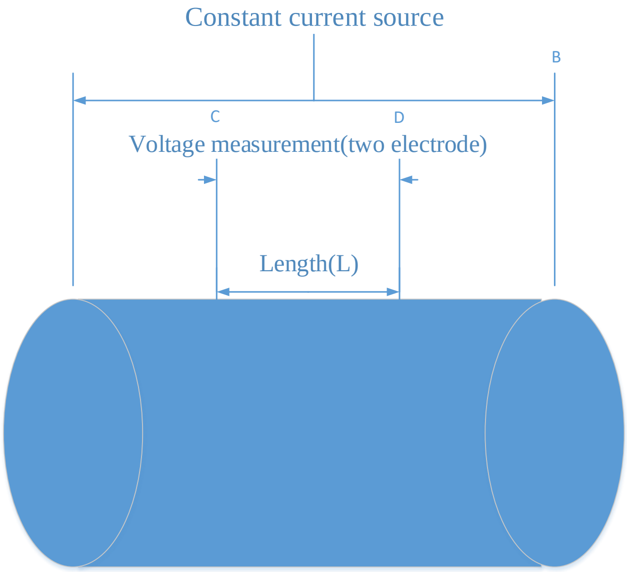


Fig. 7 The basic diagram of body segment and bio-impedance measurement, A, B apply current to human body, C and D detect the voltage change from human body
Where R is resistance of body segment,
ρ is the resistivity of the conducting material,
L and V are the length and volume of conducting material, respectively.

When ac current injected into the body segment. The body generates two types of R to impedance when there have current flow. They are resistance and reactance. The resistance is generated by extracellular fluid and intracellular fluid. The reactance is generated by cell membranes. Bio-impedance is made up by resistance and reactance together. Resistance and reactance can all detected when body segment injected current during appropriate frequency range. The majority of study of single frequency bio-impedance analysis inject electrical current to tissue at 50-KHz.

The current will flow past cell membrane、extracellular fluid and intracellular fluid when body segment injected 50-KHz current. There have several study show that the frequency will influence bio-impedance. Due to cell membrane be considered as a capacitor. When injected current at very low frequency, cell membrane act as an insulator. Thus, the current cannot pass through the cell membrane to intracellular fluid. The current flow at extracellular fluid at that moment, which is responsible for the measured R of bio-impedanceR_0. Fig. 8 shows the relationship between bio-impedance and frequency. When the current at infinite or very high frequency, the capacitor of body segment be considered as a perfect capacitor. Therefore the current will pass through the cell membrane and flow between extracellular and intracellular fluid. Thus, total body R is responsible forR_∞ which combined of the part from both intracellular and extracellular fluid.

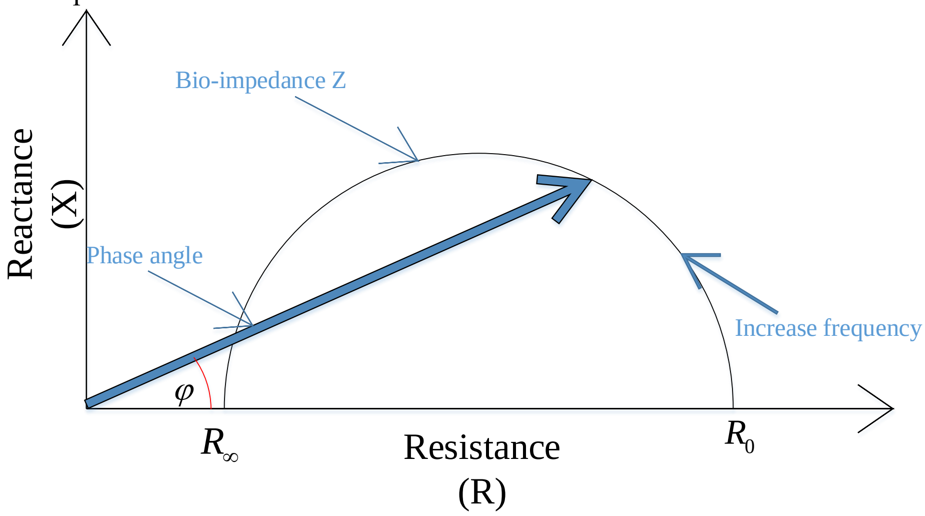


Fig. 8 Diagram of the graphical derivation of the phase angle; its relationship with resistance (R), reactance (X_c), impedance (Z) and the frequency of the applied current. R_∞ is the impedance when frequency in infinite, R_0 is the impedance when frequency in low or zero.

Since the body not fit for injected zero or infinite frequency current. Therefore, some research reveals several approaches about the effect of frequency to bio-impedance measurement. In among of these researches, single-frequency bioelectrical impedance analysis (SF-BIA) approach and multi-frequency bioelectrical impedance analysis (MF-BIA) approach are widely used.

Single frequency Bio-impedance analysis (SF-BIA) normally use 50-KHz as the frequency of the current be injected into body segment. 50-KHz for bioelectrical impedance analysis is a way to evaluate the resistivity of the total of extracellular fluid and intracellular fluid. Nonetheless, SF-BIA is not quite fit for determine difference in intracellular water.

Multi-frequency bio-impedance analysis (MF-BIA) apply different frequency current to measurement stage. MF-BIA inject 0, 1, 5, 50, 100, 200 until 500 KHz AC current to body segment to evaluate fat free mass (FFM)、total body water (TBW)、intracellular water (ICW) and extracellular water (ECW). As mentioned above, the result of the frequency not in the scope during 5 KHz and 200 KHz not have excellent reproducibility, especially when current at a low frequency, measurement of reactance not have enough accuracy. MF-BIA compare with SF-BIA have a better prediction accuracy and bias for ECW. However, SF-BIA also have its own advantage when SF-BIA compare with MF-BIA. When SF-BIA detect TBW in unhealthy subject have a better result than MF-BIA.

2.11 Evaluation of a Bio-impedance Method for Measuring Human Arm Movement [7]

A new method for measuring upper limb movement using a bio-impedance technique was proposed from this study. There have 12 normal subjects in this research, the bio-impedance changes of forearm and upper arm and joint angle of each joint were measured in this research, respectively. This thesis shows that the measured bio-impedances on each subjects are different, but there still have a highly correlated between the bio-impedances changes and joint angle changes during elbow and wrist extension and flexion. The relationships between the wrist joint angle and impedance changes of the forearm are r=0.98. The relationships between the elbow joint angle and impedance changes of the upper arm is r=-0.99, respectively. The average correlation coefficients of the wrist and elbow movement are 096±0.04 and -098±0.02, respectively.

2.12 Optimal electrode configuration of bio-impedance measurement (the effect of configuration for upper limb angle and bio-impedance changes) [42]

This study presents a four-channel impedance measurement system, which include a two-channel goniometer as a calibration tool to measure the relationship between bio-impedance changes of forearm or upper arm and joint angle changes, respectively. There have ten subjects (ages: 29±6 years) in this study. A strong dependent relationship between the impedance changes resulting from the wrist and elbow movements and electrode configurations be found. When the electrode place at the optimum position of the experiment of this study, the bio-impedance change of the forearm and wrist joint angle have heavily relationship, the bio-impedance changes of upper arm also have strong relationship between with elbow joint angle. The correlation coefficient between bio-impedance changes and joint angle of each movement are 0.95±0.04 and -097±0.03, respectively. There also has good reproducibility of the wrist and elbow impedance changes of five subjects. The optimum electrode configuration from this study would be useful for detecting the relationship between bio-impedance changes and joint angle changes.

2.13 State of the art

These papers propose the importance of frequency for bio-impedance measurement, bio-impedance equivalent model, optimal electrode configuration and the relationship between bio-impedance changing and elbow joint movement. Some researcher test 50-KHz current to bio-impedance measurement, and they found 50-KHz have good performance. In this study, 50-KHz will be applied to bio-impedance measurement, and this study will focus on the relationship between bio-impedance changes and joint angle. The researcher from literature review doesn't use the relationship between bio-impedance changes and elbow joint angle to application or interface. Thus, this study will focus on this area, and apply this relationship to application for arm amputee patient. The table 1 shows the state of the art of Bio-impedance method.

Table 1 the state of the art of bio-impedance method including bio-impedance equivalent model, the method of frequency for BIA measurement and body compartments.

Area	Method
Bio-impedance equivalent model	(1)Series-equivalent model[12] (2)Parallel-equivalent model[12]
The method of frequency for BIA measurement	(1)Single frequency method[2][11] (2)Multi-frequency method[2][11]
Body compartments	FFM; BCM; TBW; ECW; ICW[11]

Chapter 3
Methodology

This article evaluates the elbow joint movement using bio-impedance method. An analog circuit board design has been applied in this study. This study extract bio-impedance signal using injected current to human arm. Thus, the safety should be guaranteed in this study. This study applied four frequencies of current signal which consists of 20-kHz, 45-kHz, 50-kHz and 70-kHz and low intensity constant current which is 536.59 microampere to the experiments. A Wein oscillator and Howland constant current source has applied in the experiment to produce high-frequency and low-intensity current, which safety standard is supported by U.S.FOOD & DRUG organization. Human arm has different noise, such as blood flow or heart beats. Those noise is the interference of bio-impedance signal. Due to bio-impedance signal has wide frequency bandwidth, a high-pass filter has been applied in this study to filter the signal which is lower than 10-kHz. After amplify the AC signal which is correspond to bio-impedance signal, the signal has been transfer to DC signal.

There has three electrode configuration has been applied to compare the influence of different electrode configuration. Moreover, multi-frequency current and multi-subject has been applied in this study.

3.1 Bio-impedance basics

Bio-impedance is one significant electrical property of a biological tissue. The value of bio-impedance can represent the healthy degree of corresponding biological tissue. Bio-impedance can be detected when the biological tissue injected an alternating current. It is also has highly depend on frequency, tissue type and the volume changes of body tissue. Some equation used to describe the relationship between bio-impedance and muscle tissue volume are mentioned in some research [12] [13]. Single frequency bio-impedance analysis (SF-BIA) method normally measure bio-impedance at 50-KHz. According to empirical relationship are used to derive fat-free mass (FFM). Some empirical relationship between resistance of body segment and resistivity ρ and some parameter of body size as equation (26):

$$R = \rho \frac{L}{A} = \rho \frac{L^2}{V} \tag{26}$$

Where L is length, A is cross sectional area, V is the volume of the body equivalent cylinder.
Moreover, V can be substituted by $V = \frac{m}{d}$, where m and d are mass and density. Respectively.
Some research according these relationships derive an empirical equation (27) of FFM as follows:

$$FFM = C\frac{H^2}{R}. \tag{27}$$

That research also mentions that a fully empirical relationship for FFM includes extra terms [43]. Some researcher also found some of the other empirical equation as equation (28):

$$V = I(Z_m // Z_t) = I(\rho_m \frac{L}{A_m} // \rho_t \frac{L}{A_t}) \tag{28}$$

V: Voltage between electrodes
I: Constant current
L: Distance between voltage electrodes
A_m: Cross-sectional area of muscle between two voltage electrodes
A_t: Cross-sectional area of tissue
ρ_m: Resistivity of muscle

ρ_t: Resistivity of tissue
Fig. 9 shows the model of upper limb bio-impedance measurement.

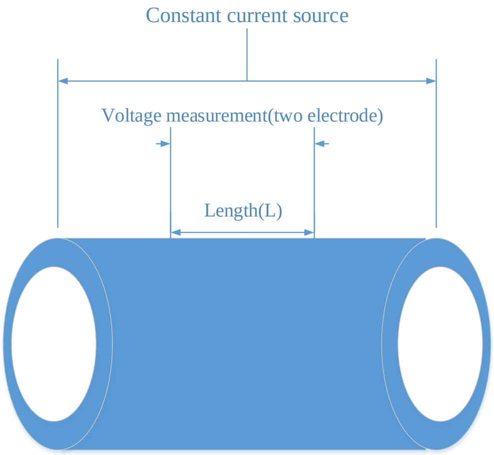


Fig. 9 upper limb include muscle and tissue used for measuring impedance change.

Bio-impedance is very sensitive to the frequency. Thus, an optimal frequency is significant for bio-impedance measurement. As previously mentioned, 50-KHz alternating current is recommended to bio-impedance measurement using the single frequency method.

3.2 Resistance and capacitance

Body segment is a complex electrical property cylinder, it not only have resistance but also have capacitance. It is due to cell membrane have capacitive. As mentioned in the literature review, when body segment be injected a low frequency constant alternating current, injected current cannot through the cell membrane to intracellular water, only flow at extracellular water. But if injected current have enough high frequency, current can pass through the cell membrane into intracellular water. Cell membrane act as capacitor when current be injected to body segment. Fig. 10 and 11 as following shows the schematic diagram of how cell membrane influence on current.

Low frequency condition:

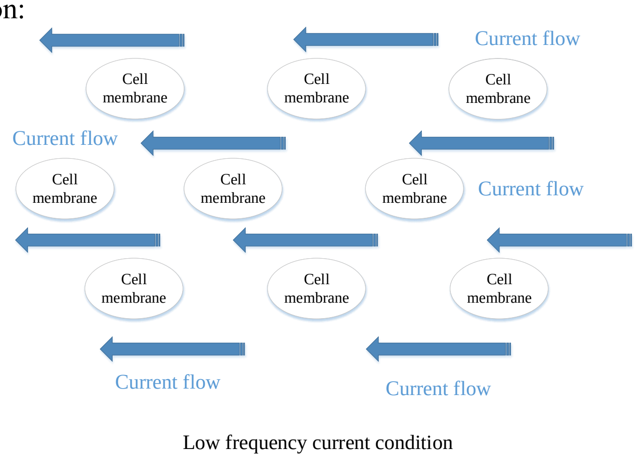
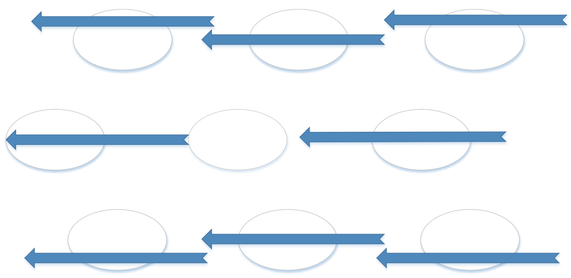


Fig. 10 The current flow when low frequency current injected into body segment and high frequency condition:



High frequency current condition

Fig. 11 The current flow when high frequency current injected into body segment

As previously mentioned [11], some research considers bio-impedance as an equivalent circuit. The series equivalent circuit is composed by a resistor R_s and a capacitor C_s. The magnitude of impedance in series equivalent can be described as equation (29):

$$Z = \sqrt{R_s^2 + \frac{1}{(2\pi fC_s)^2}} \tag{29}$$

The phase angle θ between resistance and reactance can be described as equation (30):

$$\theta = -\arctan(\frac{1}{2\pi fR_sC_s}) \tag{30}$$

Where f is the frequency; R_s is resistor of the series equivalent circuit; C_s is capacitor of the series equivalent circuit. In this study. It expresses the series equivalent circuit in term of a quantity Z^*as equation (31):

.

$$Z^* = R_s - \frac{j}{2\pi fC_s} = R_s + jX \tag{31}$$

Impedance also can be described into a parallel equivalent circuit. And resistor and capacitor of parallel model can be replaced by conductivity and permittivity, so modified magnitude and phase angle equation of this model as equation (32) (33) (34):

$$Z=[\frac{1}{\frac{1}{R_p^2}+(2\pi fC_s)^2}]^{\frac{1}{2}} \tag{32}$$

$$R_s = \frac{L}{A}[\frac{\rho}{1+(2\pi f\varepsilon_0\varepsilon'\rho)^2}] \approx \frac{L}{A}\rho \tag{33}$$

$$X = \frac{-L}{A}[\frac{2\pi f\varepsilon'\varepsilon_0\rho^2}{1+(2\pi f\varepsilon_0\varepsilon'\rho)^2}] \approx \frac{-L}{A}[2\pi f\varepsilon'\varepsilon_0\rho^2] \tag{34}$$

Where f is frequency, R_p and C_p are resistor and capacitor of parallel model, respectively. Conductivity and permittivity value are depend on frequency of the current, thus, the frequency is key role at bio-impedance measurement and analysis. Due to 50-KHz current have good performance for bio-impedance measurement [2], thus, 50-Khz alternating current will be used in this thesis.

3.3 Electrode configuration

Two-channel bio-impedance measurement system was widely used in many previous researches [7, 10, 12, 13, 42]. Two-channel measurement system is optimized in this article. A one-channel Bio-impedance measurement system and a goniometer were applied for this study. Two electrodes apply the constant current from modified Howland constant current source to arm and extract the voltage to amplifier INA128. The hypothesis of this study is the electrode configuration has effect on bio-impedance measurement. Moreover, it find that whether the muscle would has effect on correlation measurement. Thus, this study consider the electrode configuration of some previous study [15] and the influence of biceps brachii and triceps. This study combine the electrodes 1 and 5, 2 and 3, 1 and 4 as shown in Fig. 2. Electrode 1 and 5 were attached on the lateral and medial plane, electrode 2 and 3 were attached on frontal plane, and electrodes 1 and 4 were attached on medial and lateral plane. Electrode 6 is reference position and it was attached on frontal plane of forearm where near the inside of palm. Fig. 12 show the electrode configuration in this bio-impedance measurement.

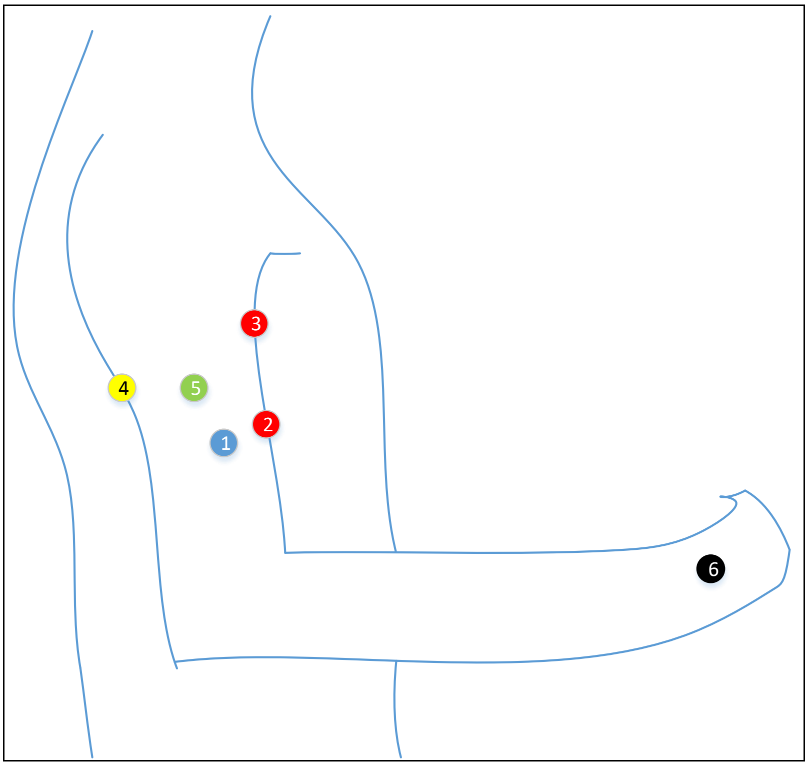


Fig. 12 The electrode configuration in the human bio-impedance measurement.

Thus, the criteria of optimum electrodes pair configuration have two important rules as follows [42]:

(i) A high correlation coefficient between Bio-impedance changes and joint angle.

(ii) High signal-to-noise (SNR) of Bio-impedance changes, where the signal is the magnitude of the impedance change.

3.4 Hardware design

Fig. 13 shows the block diagram of the device for bio-impedance measurement. A modified Wien oscillator will be applied to generate sine waves. LF412CN operation amp will be applied to Wien-bridge oscillator (Wein OSC), due to its good frequency response. After this device collects the signal and process the signal, the voltage of body segment can be collected. 10 KΩ reference resistor is used in this device.

In the literature review, each 10cm tissue of the forearm has 40Ω bio-impedance, but in the practical, the value of bio-impedance will more higher than 40Ω. It is caused by the impedance of electrodes. i.e., in the range of 200Ω to 500Ω [10]. The value of upper arm impedance has 55Ω-80Ω in some researcher's result [7].

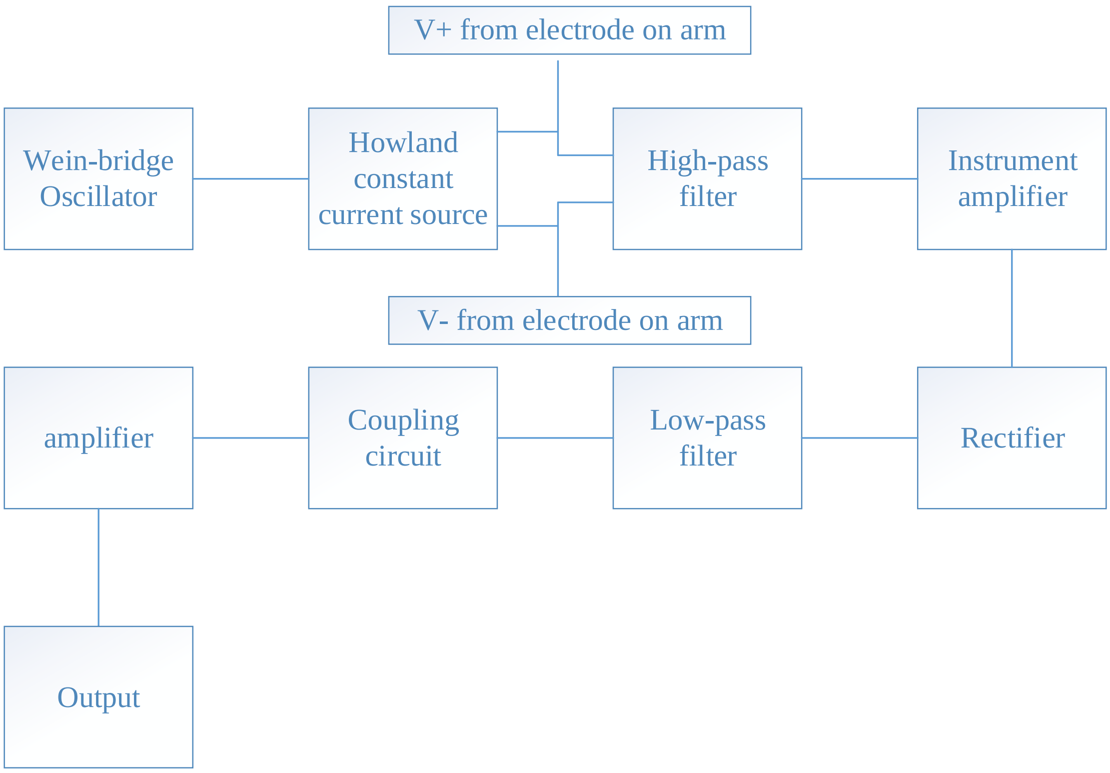


Fig. 13 Design of hardware for BIA measurement

3.5 current source design

Bio-impedance signal have wide bandwidth. Constant current design should consider this property. Therefore, high output impedance and wide frequency band are necessary for the current source design. This thesis uses a wide frequency band and low noise amplifier LF41CN to build modified current circuit as Fig. 14.

Wein-bridge oscillator is used in this experiment. This oscillator is a type of electronic oscillator that generates sine waves. It can generate a large range of frequencies. The oscillator is based on a bridge circuit originally developed by Max Wien in 1891 for the measurement of impedances. The bridge comprises four resistors and two capacitors. The oscillator can also be viewed as a positive gain amplifier combined with a band-pass filter that provides positive feedback. Automatic gain control, intentional non-linearity and incidental non-linearity limit the output amplitude in various implementations of the oscillator. Figure 11 show the basic diagram of Wien-bridge oscillator.

The circuit shown to the right depicts a common implementation of the oscillator, with automatic gain control, using modern components. Under the condition that $R_1=R_2=R$ and $C_1=C_2=C$, the frequency of oscillation is given by equation (35):

$$f = \frac{1}{2\pi RC} \tag{35}$$

And the condition of stable oscillation is given by equation (36):

$$R_b = \frac{R_f}{2} \tag{36}$$

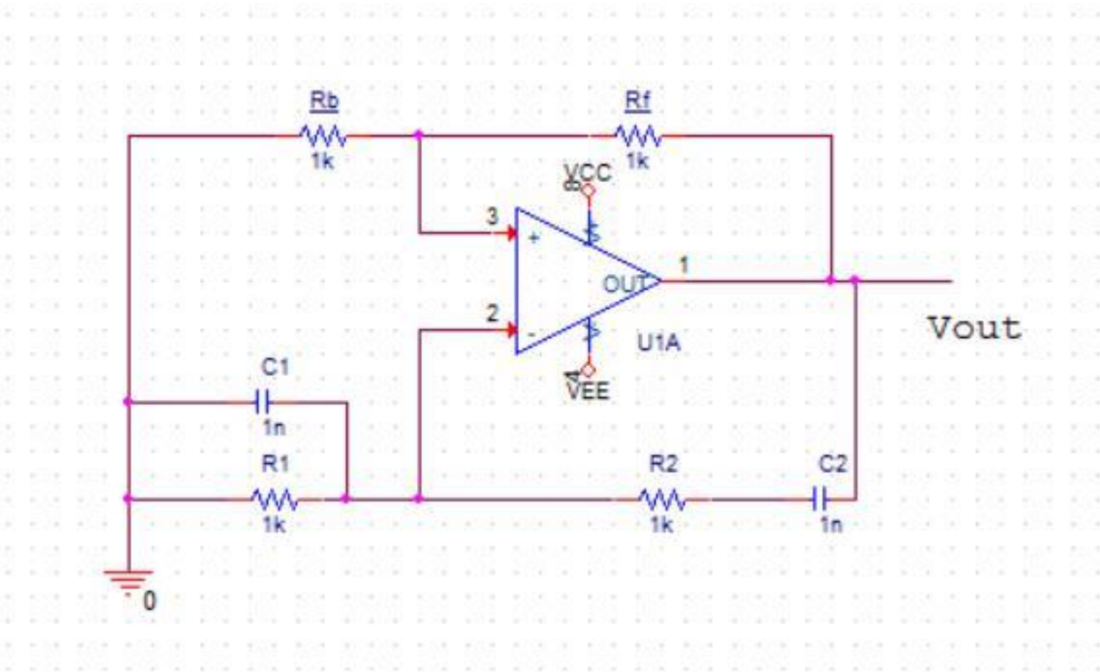


Fig. 14 In this version of the oscillator, R_b is a small incandescent lamp. Usually R1 = R2 = R and C1 = C2 = C. In normal operation, R_b self-heats to the point where its resistance is $R_f/2$.

After oscillator circuit, there has a modified Howland constant current source. The Oscillator will generate the sine wave voltage signal to modify constant current source circuit as Fig. 15.

When modified Howland current source circuit meets the following condition as equation (37):

$$\frac{R_2}{R_4} = \frac{R_7}{R_5} \tag{37}$$

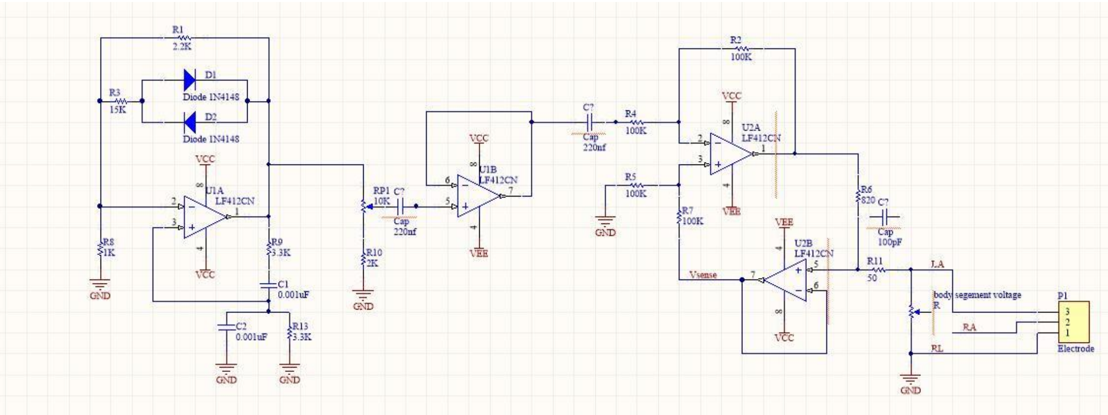


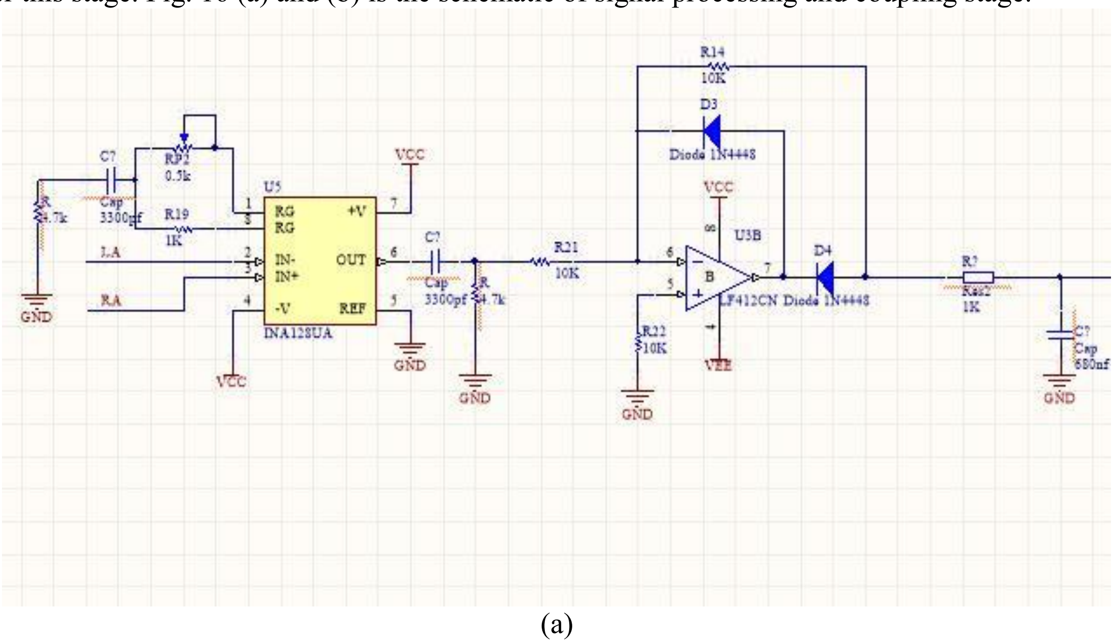
Fig. 15 Modified Wien-bridge oscillator and Modified Howland constant current source design

The output impedance$R_O = \infty$. Moreover, the circuit output (load current) will got by following equation (38):

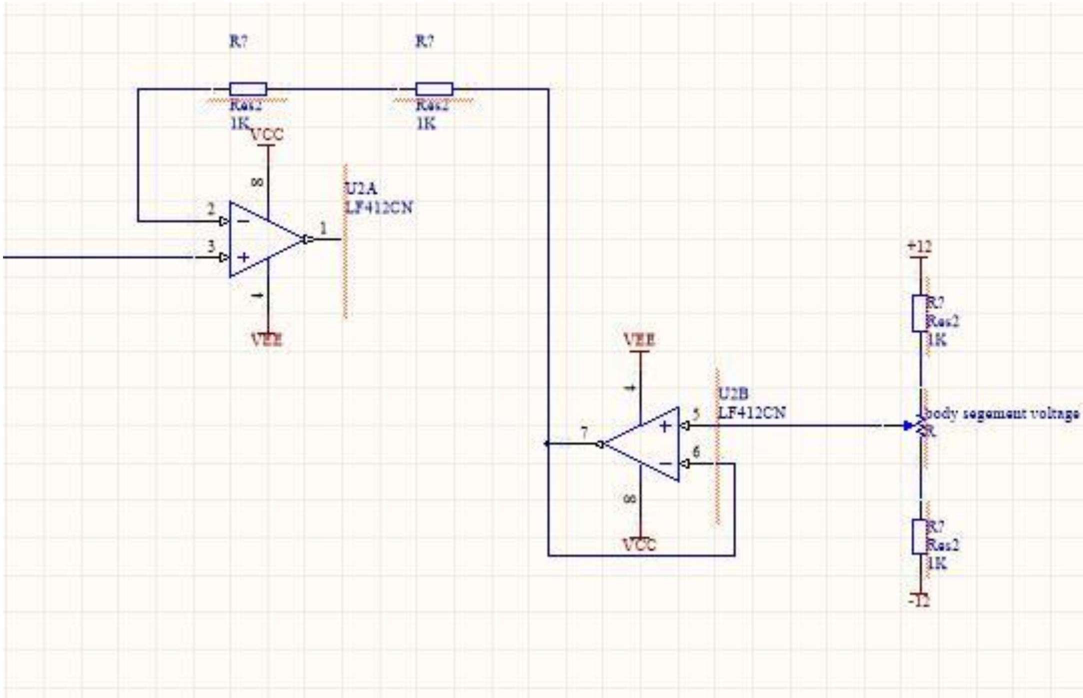
$$I_R = \frac{V}{R_6} \tag{38}$$

Where V is the root mean square value of output of the oscillator circuit in last stage.

I_R is the current of load R from body segment. The output of Howland constant current source is 536.59 microampere. This intensity fits the U.S.FOOD & DRUG safety standard. This thesis through measuring the voltage of human arm to evaluate the corresponding bio-impedance. Thus, there has some noise from arm surface, such as: blood flow, heart beats and 50-Hz noise. High-pass filter has been applied in the study to improve the arm surface condition. This study set it after the output of instrument amplifier INA 128. The cut-off frequency of high-pass filter is 10264.44 Hz. INA 128 is a low power, the general purpose instrumentation amplifier offering excellent accuracy. It is used for enlarge the collected at last stage voltage. The half-wave rectifier and low-pass filter has been applied in this study to transfer AC signal to DC signal after the stage of instrument amplifier INA 128. The cut-off frequency of low-pass filter is 234.05 Hz. There has a DC coupling circuit and amplifier circuit after this stage. Fig. 16 (a) and (b) is the schematic of signal processing and coupling stage.



(a)



(b)

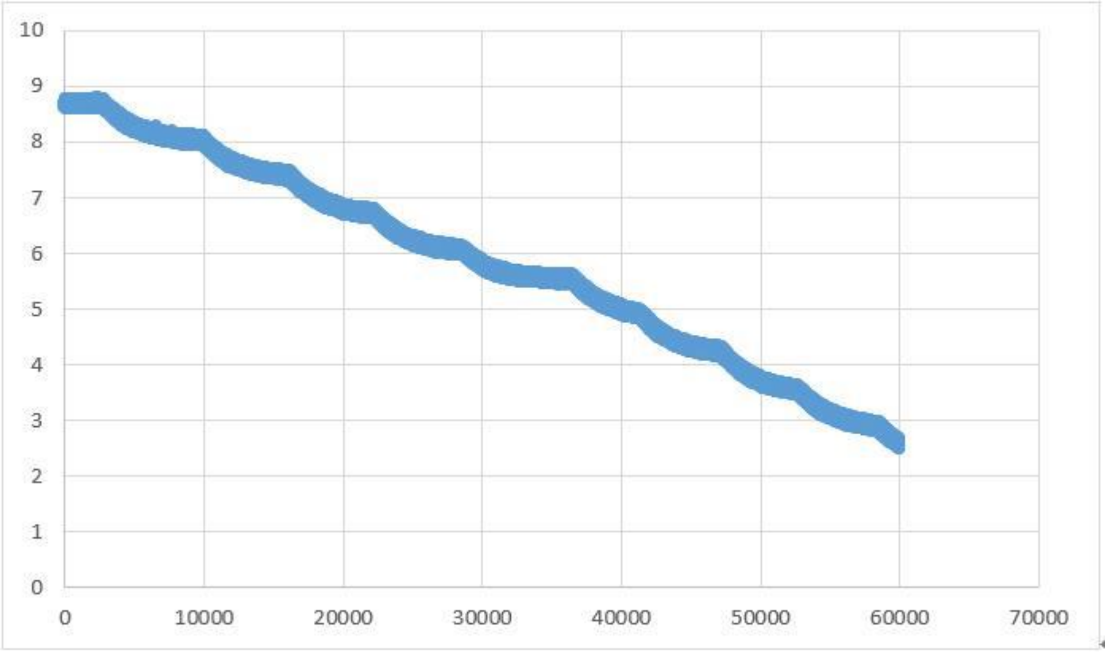
Fig. 16 (a) and (b) The diagram is designed for signal processing, where the output of (a) connect with the input of (b)

3.6 Preliminary result and conclusion

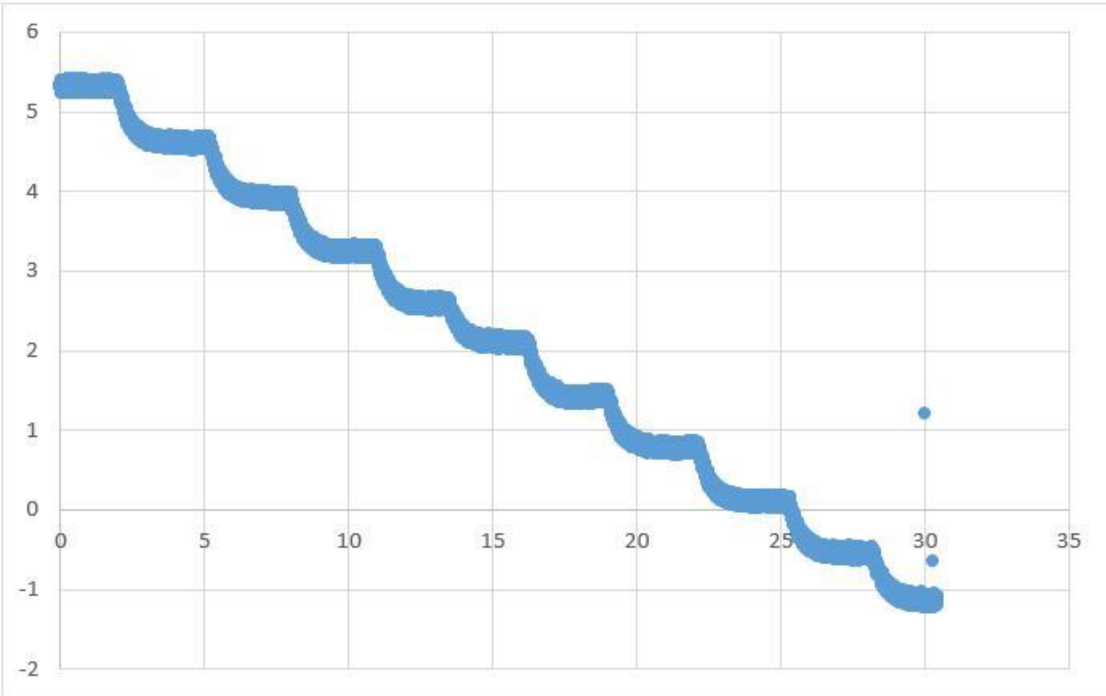
This thesis makes a pre-experiment using a resistor box instead of body segment and set the start value at 1K**Ω** . Then, the resistor box is changes its value every 10**Ω** per times.

National instruments data acquisition NI USB-6009 used for collecting voltage signal corresponding resistance changes from resistor box. The signal collected by National instruments NI USB-6009 is recorded in software LabVIEW.

Figure.17. show the result of pre-experiment. The X axis in the coordinate is time, and the Y axis in the coordinate is the voltage of bio-impedance. This experiment will change the value of resistor box and hold this value during less time. 10**Ω** as the changes of resistor box value was applied to this experiment. The initial resistor value of both experiments is 1 K**Ω** . However, the initial impedance value is different. Although the initial impedance value is different, the impedance value changes are similar. Both of result use 1 K**Ω** as reference resistor. However, the start value of result for each experiment are different. In Fig. 17 (a). The start value of voltage is approximately equal to 8.668 V. the voltage change in (a) are approximately equal to 0.6V. In Fig. 17 (b). The start value of voltage is approximately equal to 5.18V. The voltage changes in (b) are approximately equal to 0.7V. The result show the current of this modified Howland current circuit is constant and the similar resistor value changes will cause similar voltage changes.



(a)



(b)

Fig. 17 (a) and (b) The result of bio-impedance changes measurement

Chapter 4
Experiment setting and result

4.1 Single Subject and multi-frequency bio-impedance analysis

4.1.1 Overview

In this part of experiment, one subject had measured his bio-impedance changing with elbow joint angle changing. There has four experiment in single subject bio-impedance measurement: 20-kHz, 45-kHz, 50-kHz and 70-kHz bio-impedance measurement. 45-kHz experiment is relative different with another experiment. It consists of 9 stage in elbow joint angle movement. 20-kHz, 50-kHz and 70-kHz experiment consists of 4 stage in elbow joint angle movement. Pearson correlation equation and T-test has applied in this study to analysis the results.

Due to 45-kHz experiment is the preliminary experiment for the human bio-impedance measurement. The object of 45-kHz is that this study evaluate the joint angle using bio-impedance signal. Thus, we applied a goniometer to evaluate the joint angle and measure the bio-impedance using the BIA device as Fig. 10. The result of 45-kHz is relative reliable, it proves the bio-impedance signal is useful in the evaluation of joint angle. However, the result of 45-kHz has high standard deviation. The experiment setting has changed in other experiments: There has a 4 stage joint angle movement to optimize 9 stage movement in joint angle measurement. It made the interference of standard deviation from 9 stage setting become smaller.

This article evaluate the bio-impedance response using multi-frequency. The object of multi-frequency experiment is we try to find some suitable frequency to evaluate the joint angle movement using bio-impedance signal, we want to check whether multi-frequency experiment setting has interference to the correlation between bio-impedance changing and elbow joint angle movement.

The result of 20-kHz bio-impedance measurement with elbow joint angle movement measurement is not stable. The detail as following chapter. There has stable result from 45-kHz and 70-kHz experiment.

In the single subject and multi-frequency bio-impedance measurement. Those experiment prove that bio-impedance signal is useful to evaluate the elbow joint angle movement. 45-Khz, 50-kHz and 70-kHz is the suitable frequency in this case of study.

In the preliminary, 45-kHz injected constant current has applied in the bio-impedance measurement. However. There has three limitations. First, only one frequency has applied in the preliminary experiment. Second, only one subject join the experiment. Third, there has no consideration about the body parameter, such as: Body mass index (BMI).

In the chapter 6.1. This article solve a limitation of preliminary experiment. We applied multi-frequency to the experiment. Moreover, the most of frequency got stable result from correlation measurement.

The fig. 18 (a) and (b) shows that the start and end of motion. Where the motion is start at 0 degree and end at 90 degree for elbow flexion motion, the extension motion is start at 90 degree and end at 0 degree.

Fig. 18 (a) and (b) The motion of elbow joint is from 0 degree to 90 degree as flexion motion and 90 degree to 0 degree as extension.

4.1.2 Subject Setting

The subject is 1.70 meter and 80 kg. The gender of the subject is a male. The fat percentage of the subject is 26.5% when he join the experiment. All the data in this part of experiment was happened at the steady heart rate period. The subject is 23 years old and he is health people.

The correlation measurement in this article is calculate by Pearson correlation equation as equation (39):

$$\rho(X,Y) = \frac{\mathrm{Cov(X,Y)}}{\sigma X \sigma Y} \tag{39}$$

Where:
Cov is the covariance.
σ is the standard deviation.

4.2 45-kHz bio-impedance measurement

4.2.1 Experiment setting

This article applied 45-kHz current to human arm and measure the upper arm impedance. The elbow joint angle changing was measured at same time. 45-kHz bio-impedance measurement find the correlation between the joint angle changing of elbow movement and bio-impedance changing. Hence, all equipment must be grounded and the subjects need to clean their arms, subjects clean their arm using ethyl alcohol (70%). The degree of elbow movement consists of 9 stage for elbow flexion and extension, each elbow flexion or extension movements were repeated three times for each electrodes configuration.

The motion consists of 9 stage for elbow flexion or extension movements. Subjects sat on the chair and move their arm to 0 degree without finger flexed. This position is used as the initial position. Subjects lifted their arm in every 10 degree until 80 degree and hold on their arm 15 to 20 seconds in each position. The stage of flexion and extension movements are 0 to 80 degree and 80 to 0 degree, respectively.

4.2.2 Result

There have high correlation between joint angle movement and bio-impedance changing for each electrode configuration as Fig. 18 and 19. The correlation (R) from elbow flexion movement for three electrode configurations are 0.993, 0.989 and 0.994, respectively. The correlation from elbow extension movement for three electrode configurations are -0.997, -0.998 and 0.993, respectively.

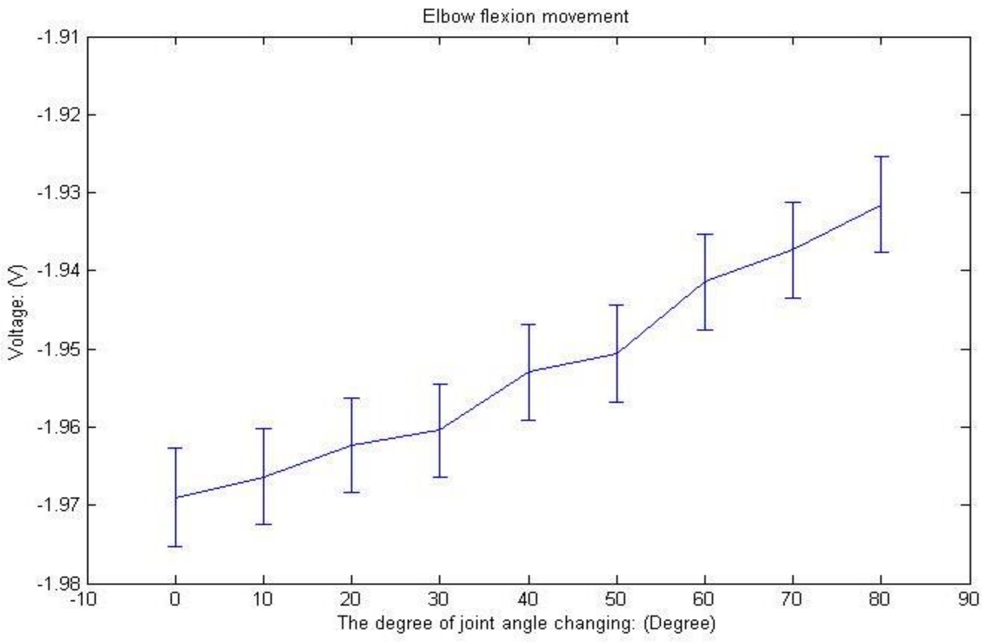


Fig. 19. The result of bio-impedance changing with elbow flexion movement from 0 degree to 80 degree. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

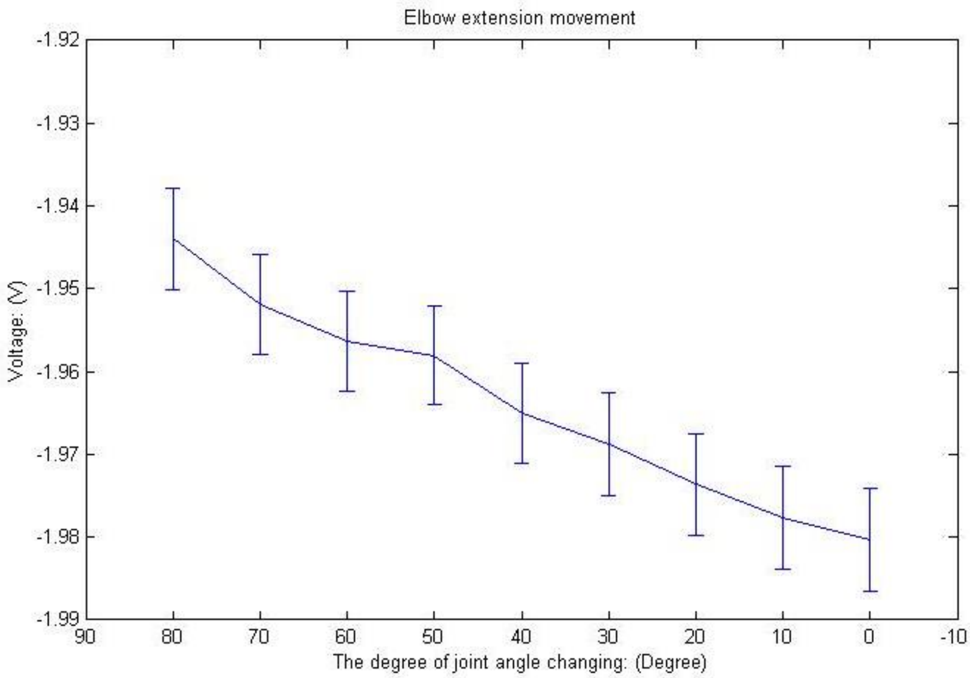


Fig. 20. The result of bio-impedance changing with elbow extension movement from 80 degree to 0 degree. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

4.2.3 Conclusion and discussion

This study measure the correlation between joint angle movement and bio-impedance changing using one channel measurement system. According to the reference, the frequency of injected current and electrode configuration will influence the bio-impedance measurement. However, this study has found that different electrode configuration has influence on initial value of bio-impedance signal and its changing value, however, it has less influence on the measurement of correlation between bio-impedance changing and joint angle changing of elbow movement. Three limitation is existed in this study due to this study is a preliminary study. The first limitation is only one subject was studied. The second limitation is caused by this study applied a fixed frequency (45-kHz) current to human arm, there has shown response from 45-kHz alternating current. However, it may have other frequencies of alternating current to optimize the result. The third limitation is caused by this study don't have any concern of some body parameters, such as body mass index (BMI). This study will find the difference of result from multi-frequency and multi-subjects in future to improve first and second limitations. Moreover, this study will consider that how the body factor influences the correlation between bio-impedance changing and joint angle movement to improve the third limitation.

4.3 20-kHz bio-impedance measurement

4.3.1 Experiment setting

This article adjust the output of Wein oscillator and get the injected current in 20-kHz. The motion in this experiment consists of four stage. The motion consists of 4 stage for elbow flexion or extension movements. Subjects sat on the chair and lifted their arm in every 30 degree until 90 degree and hold on their arm 15 to 20 seconds in each position. The stage of flexion and extension movements are 0 to 90 degree and 90 to 0 degree, respectively.

4.3.2 Result and conclusion

The result of the experiment using 20-kHz applied current was not stable in this case. This study has made a validation for 20-kHz condition to identify the reason of unstable result from 20-kHz condition. A pure variable resistor with the bio-impedance measurement circuit was applied in this case. Moreover, this study adjust 20-kHz to 70-kHz condition in this circuit. The result of verification with 20 kHz and 70 kHz using variable pure resistor are stable. But in the case of human arm the result of frequency 20 kHz is not stable because the limitation of body composition, thus, 20-kHz is not fit in this case of study.

4.4 50-kHz bio-impedance measurement

4.4.1 Experiment setting

Due to previous work of this study applied 45-kHz current to the bio-impedance measurement. Thus this article apply the frequency of applied current which is near 45-kHz to human arm and measure the bio-impedance changing with elbow joint angle movement. The motion standard of 50-kHz is same as 20-kHz and 70-kHz. There has four stage in the elbow flexion or extension motion: it begin at 0 degree and the subject move their arm 30 degree and hold on their arm some seconds in each time until 90 degree. Thus, the stage of elbow flexion movement has 0, 30, 60 and 90 degree. The stage of elbow extension movement has 90, 60, 30 and 0 degree.

4.4.2 Result and conclusion

The result of flexion motion (50-kHz) in each electrode configuration condition is 0.998, 0.982 and 0.994, respectively. The result of extension motion (50-kHz) in each electrode configuration condition is -0.995, -0.966 and -0.983, respectively. There has high correlation between bio-impedance measurement using 50-kHz and elbow flexion and extension movement. According to the result, these three electrode has not significant influence on the correlation measurement. The result of 50-kHz bio-impedance signal measurement with elbow flexion and extension as Fig. 20 and Fig. 21.

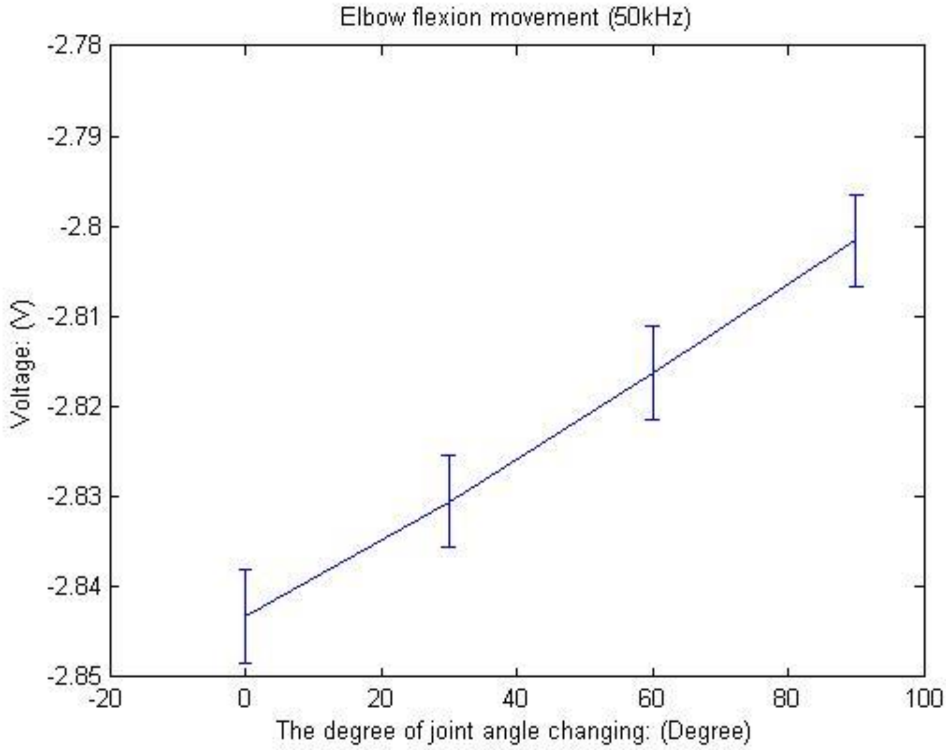


Fig.21 The result of bio-impedance changing with elbow flexion movement from 0 degree to 90 degree

in 50-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

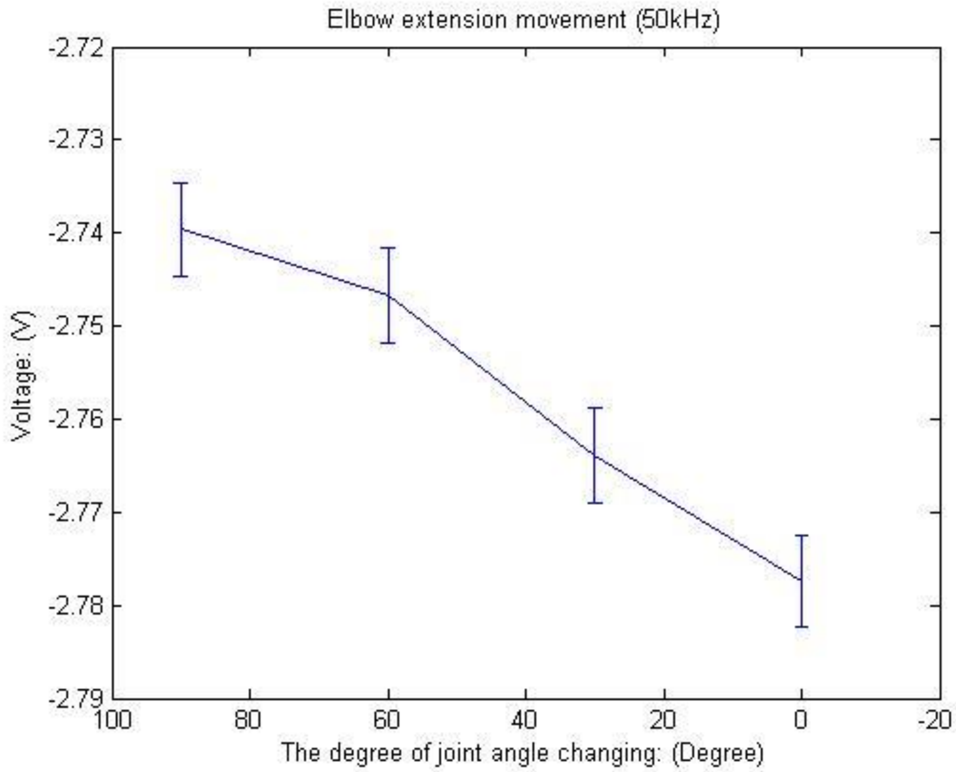


Fig. 22 The result of bio-impedance changing with elbow extension movement from 0 degree to 90 degree in 50-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

4.5 70-kHz bio-impedance measurement

This study had test relative low frequency (20-kHz), middle frequency (45-kHz, 50-kHz) in the bio-impedance measurement with elbow flexion and extension movement in this case. A relative high frequency was applied in this case of study to evaluate the elbow flexion and extension movement. 70-kHz applied current was used in this experiment. The experiment setting of 70-kHz is same as 20-kHz and 50-kHz bio-impedance measurement.

4.5.1 Result and conclusion

The result of flexion motion (70-kHz) in each electrode configuration condition is 0.987, 0.994 and 0.981, respectively. The result of extension motion (70-kHz) in each electrode configuration condition is -0.999, -0.985 and -0.987, respectively. There has high correlation between bio-impedance measurement using 70-kHz and elbow flexion and extension movement. The electrode has no significant influence on 70-kHz bio-impedance measurement and elbow flexion and extension movement, which is same as the result of 45-kHz and 50-kHz bio-impedance measurement. The result of 70-kHz experiment as shown in Fig. 22 and 23.

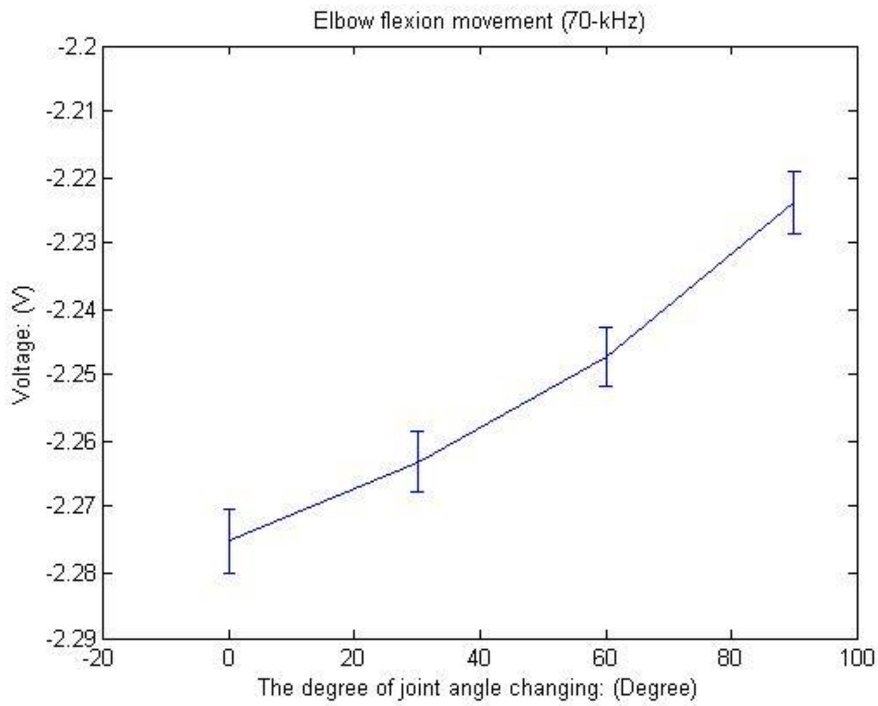


Fig. 23 The result of bio-impedance changing with elbow flexion movement from 0 degree to 90 degree in 70-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

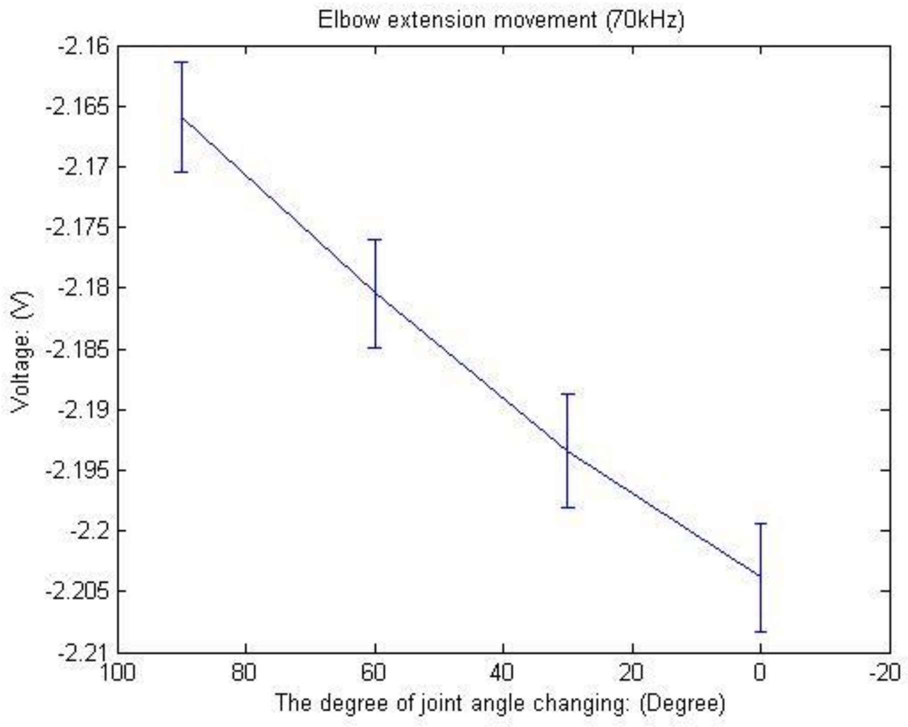


Fig. 24 The result of bio-impedance changing with elbow extension movement from 0 degree to 90 degree in 70-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

4.6 Multi-Subject Bio-impedance analyze with elbow joint angle measurement (70-kHz)

4.6.1 Overview

In this chapter, we try to solve the second and third limitation of preliminary experiment. The chapter 6.2 conclude the experiment which consists of multi-subject and different body parameter (BMI) between each subject. Thus, there has three subjects join the experiment. Three subjects consists of two female, one male. Due to the subject of chapter 6.1 is relative fat than standard. Thus, the other male subject is relative thin. Two female subjects has relative different body mass index too in the experiment of this chapter.

The circuit design is same as the 70-kHz bio-impedance measurement setting. It is due to 70-kHz is a suitable frequency to collect the bio-impedance signal and evaluate the joint angle movement.

The standard of the experiment in chapter 6.2 is whether there has enough high correlation between the bio-impedance changing and joint angle changing. Pearson correlation equation and T-test has applied in this study to analysis the results.

The first subject result is from chapter 6.1. His result of 70-kHz bio-impedance measurement was compared with other subjects in this chapter.

4.6.2 Experiment setting

The multi-subject experiment use the result of first subject from 70-kHz bio-impedance measurement from chapter 6.1. Thus, other subjects should use same standard to measure bio-impedance signal and evaluate their elbow joint angle movement. The motion standard of 70-kHz is same as 20-kHz and 50-kHz. There has four stage in the elbow flexion or extension motion: it begin at 0 degree and the subject move their arm 30 degree and hold on their arm some seconds in each time until 90 degree. Thus, the stage of elbow flexion movement has 0, 30, 60 and 90 degree. The stage of elbow extension movement has 90, 60, 30 and 0 degree.

The electrode configuration is same as chapter 6.1. Three electrode configuration has applied in multi-subject experiment.

4.6.3 Subject setting

Except for the first subject, the participant of this study consists of three male subjects and two female subjects. Thus, whole subjects condition as table 2:

Table 2 The body parameter and its mean and standard deviation value of whole subjects in this article

Subject number	Gender	Height: cm	Weight: kg	Age: years	Fat percentage
1	Male	170.00	80.00	23.00	26.50%
2	Male	170.00	54.00	59.00	23.60%
3	Male	174.00	60.00	22.00	17.90%
4	Male	175.00	64.00	22.00	19.60%
5	Female	165.00	80.00	22.00	37.60%
6	Female	165.00	49.00	22.00	21.40%
MEAN		169.83	64.50	28.33	24.43%
SD		3.89	11.91	13.72	6.50%

4.6.4 Result and conclusion

4.6.4.1 Male subjects

4.6.4.1.1 Subject 1

In this chapter, we don’t repeat the result of first male subject, which has mentioned in the chapter 6.1.

4.6.4.1.2 Subject 2

The second male subject has stable result using 70-kHz bio-impedance. The correlation between bio-impedance changing and joint angle movement in different electrode configuration as following: The correlation measurement result from elbow flexion movement is 0.991, 0.996 and 0.999. The correlation measurement result from elbow extension movement is -0.981, -0.997 and -0.989. The electrode configuration has no significant influence on the multi-subject and 70-kHz bio-impedance measurement. The result of subject 2 is as Fig. 24 and 25.

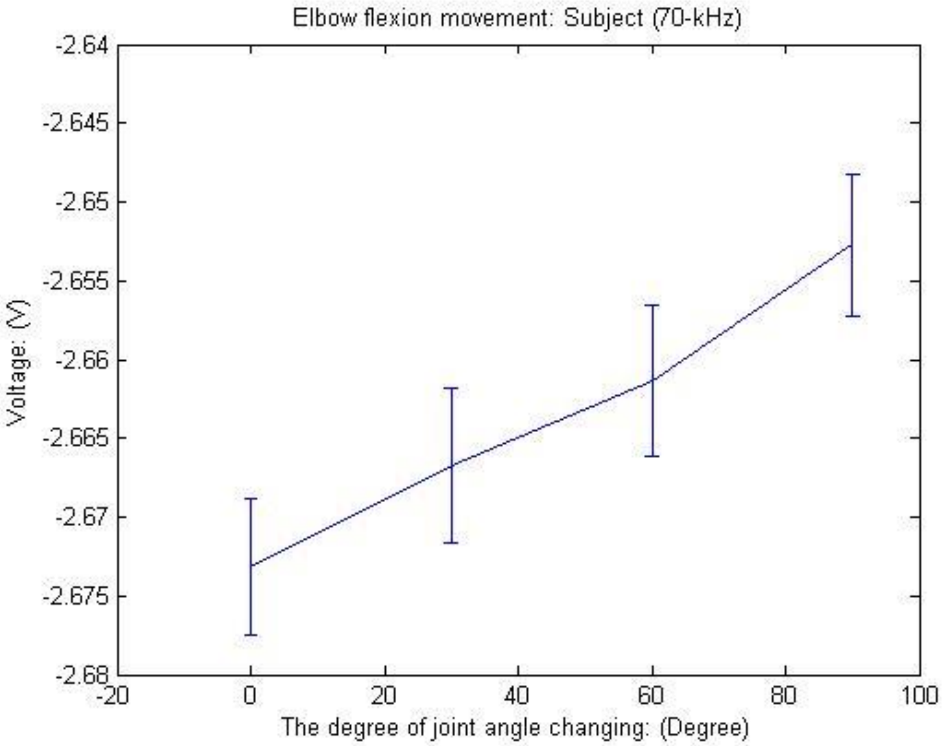


Fig. 25 The result of flexion movement in 70-kHz from male subject 2

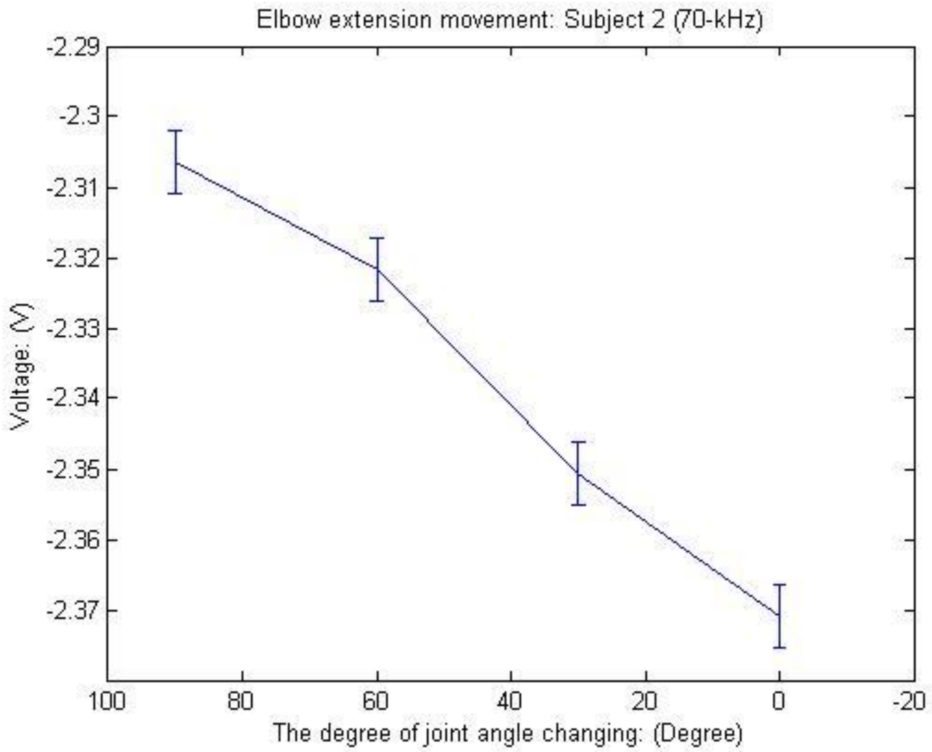


Fig. 26 The result of extension movement in 70-kHz from male subject 2

4.6.4.1.3 Subject 3

The third male subject has stable result using 70-kHz bio-impedance. The correlation between bio-impedance changing and joint angle movement in different electrode configuration as following: The correlation measurement result from elbow flexion movement is 0.997, 0.997 and 0.997. The correlation measurement result from elbow extension movement is -0.999, -0.953 and -0.938. The electrode configuration has no significant influence on the multi-subject and 70-kHz bio-impedance measurement due to each configuration got high correlation result. The result of subject 3 is as Fig. 26 and 27.

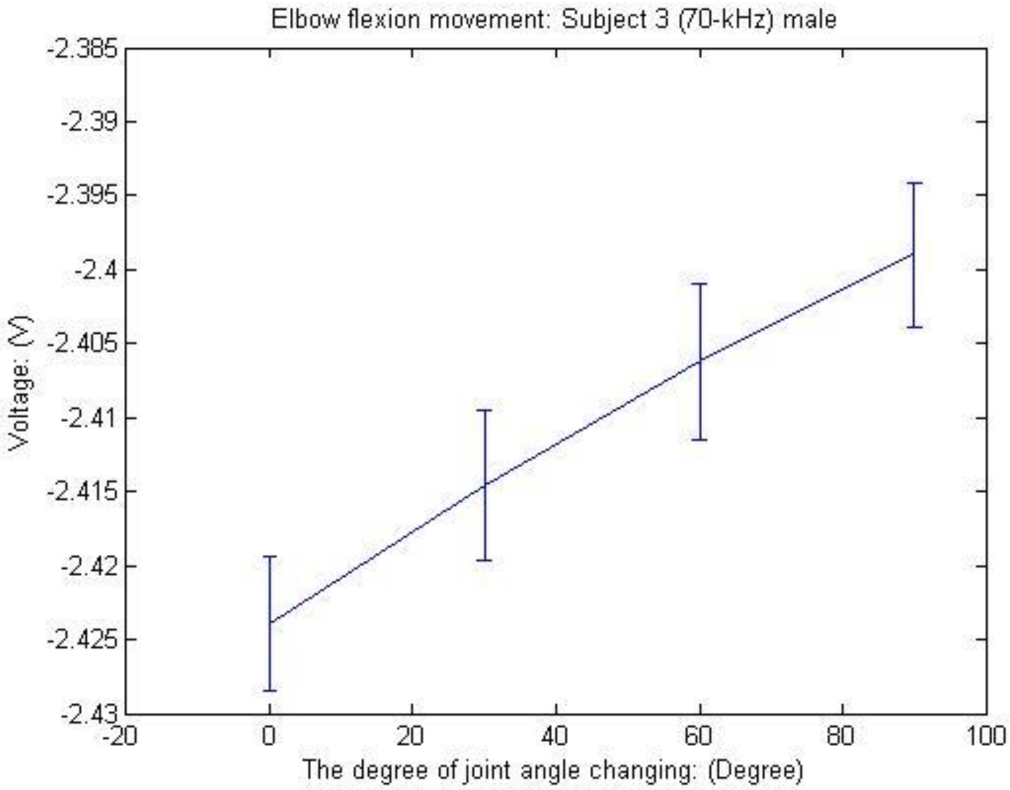


Fig. 27 The result of flexion movement in 70-kHz from male subject 3

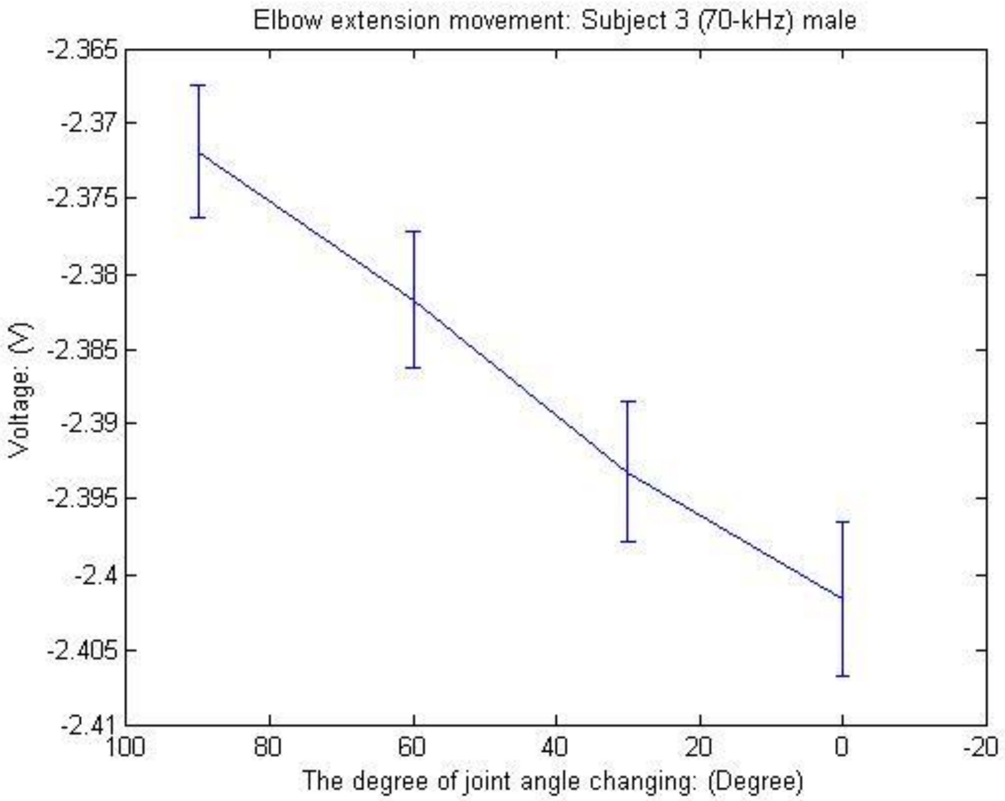


Fig. 28 The result of extension movement in 70-kHz from male subject 3

4.6.4.1.4 Subject 4

The fourth male subject has stable result using 70-kHz bio-impedance. The correlation between bio-impedance changing and joint angle movement in different electrode configuration as following: The correlation measurement result from elbow flexion movement is 0.987, 0.981 and 0.99. The correlation measurement result from elbow extension movement is -0.979, -0.975 and -0.976. The electrode configuration has no significant influence on the multi-subject and 70-kHz bio-impedance measurement due to each configuration got high correlation result. The result of subject 4 is as Fig. 28 and 29.

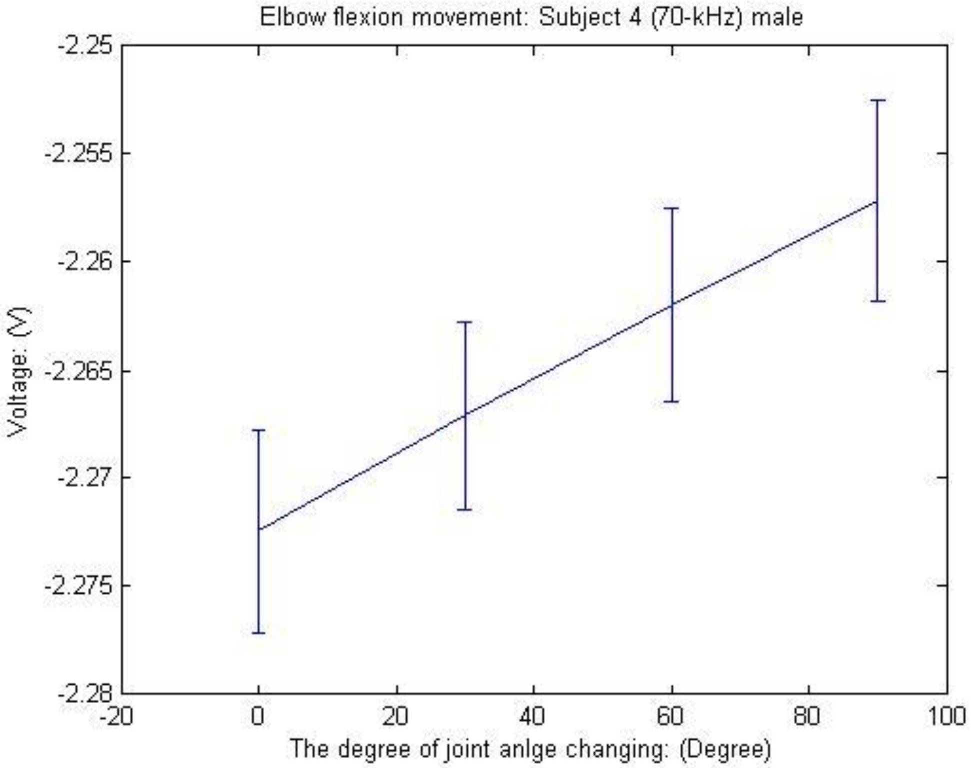


Fig. 29 The result of flexion movement in 70-kHz from male subject 4

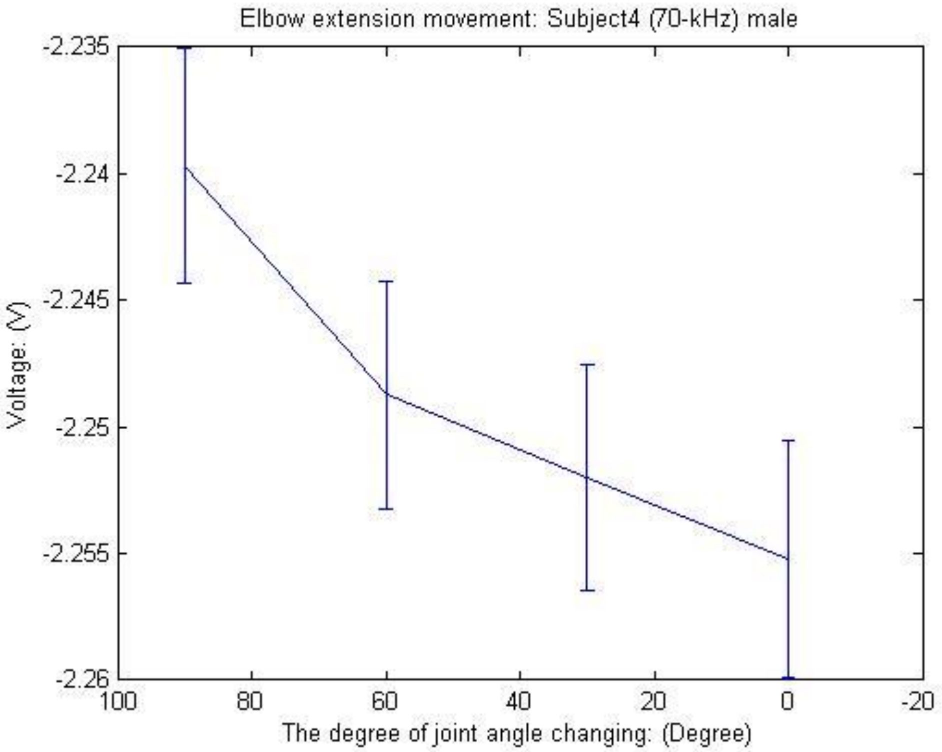


Fig. 30 The result of extension movement in 70-kHz from male subject 4

4.6.4.2 Female subjects

4.6.4.2.1 Subject 1

The first female subject has stable result using 70-kHz bio-impedance. The correlation between bio-impedance changing and joint angle movement in different electrode configuration as following: The correlation measurement result from elbow flexion movement is 0.995, 0.982 and 0.999. The correlation measurement result from elbow extension movement is -0.986, -0.981 and -0.972. The electrode configuration has no significant influence on the multi-subject and 70-kHz bio-impedance measurement due to each configuration got high correlation result. The result of subject 1 is as Fig. 30 and 31

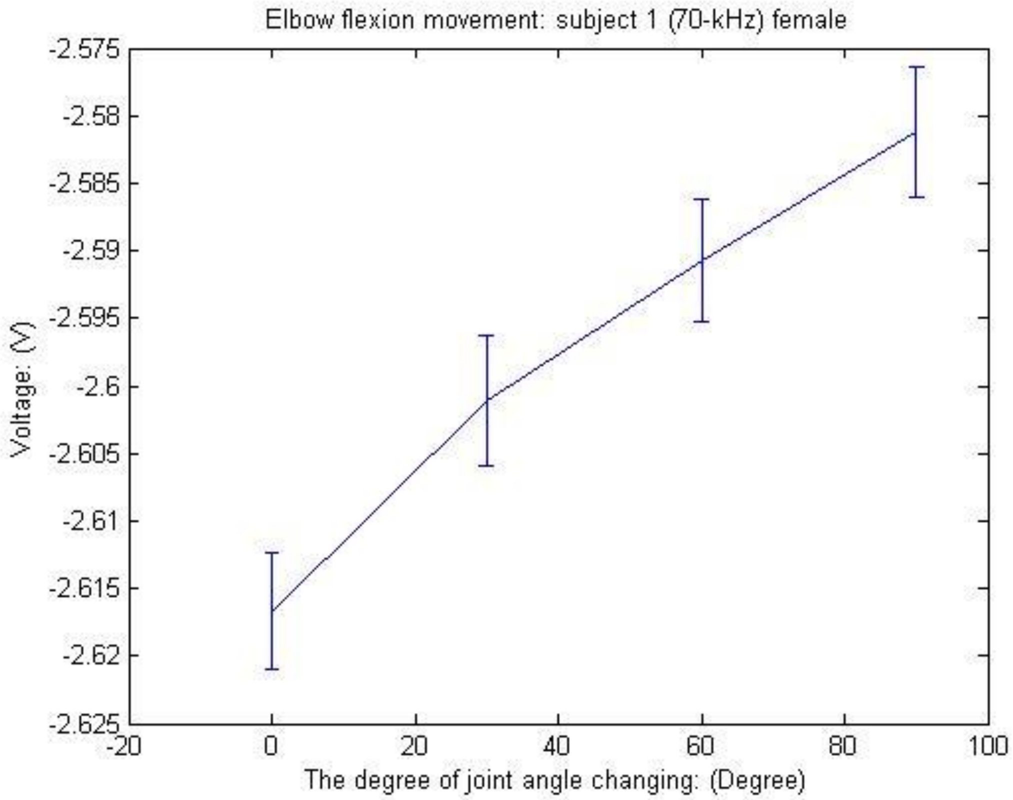


Fig. 31 The result of flexion movement in 70-kHz from female subject 1

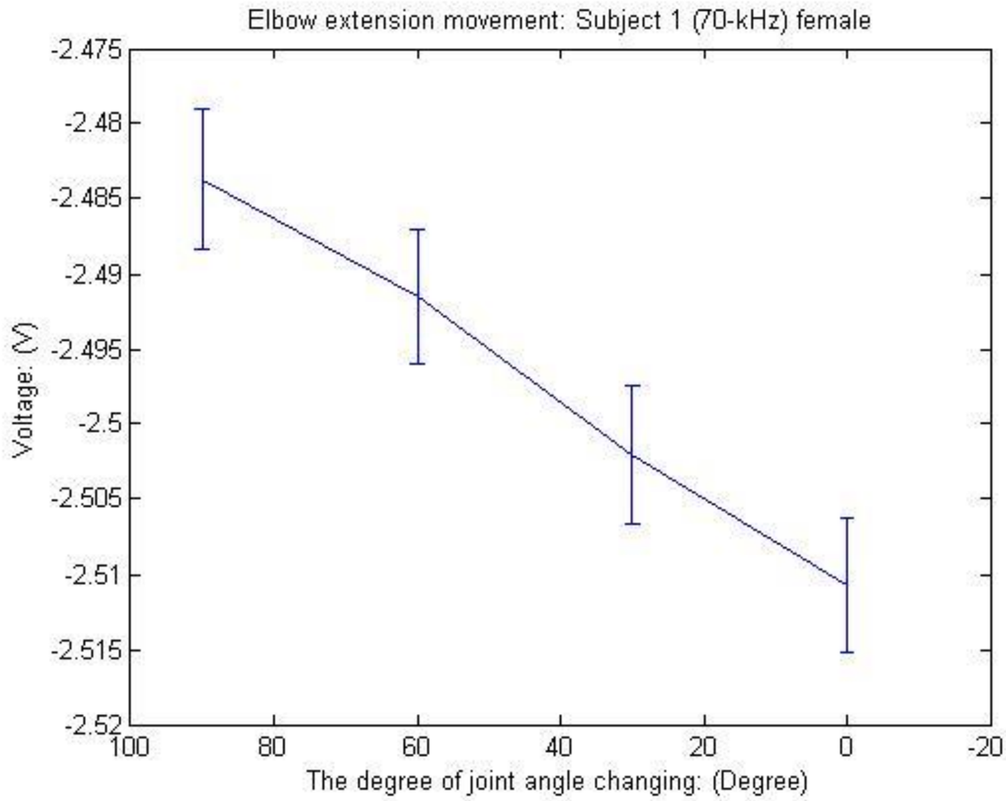


Fig. 32 The result of extension movement in 70-kHz from female subject 1

4.6.4.2.2 Subject 2

The first female subject has stable result using 70-kHz bio-impedance. The correlation between bio-impedance changing and joint angle movement in different electrode configuration as following: The correlation measurement result from elbow flexion movement is 0.995, 0.961 and 0.985. The correlation measurement result from elbow extension movement is -0.97, -0.992 and -0.996. The electrode configuration has no significant influence on the multi-subject and 70-kHz bio-impedance measurement due to each configuration got high correlation result. The result of subject 2 is as Fig. 32 and 33.

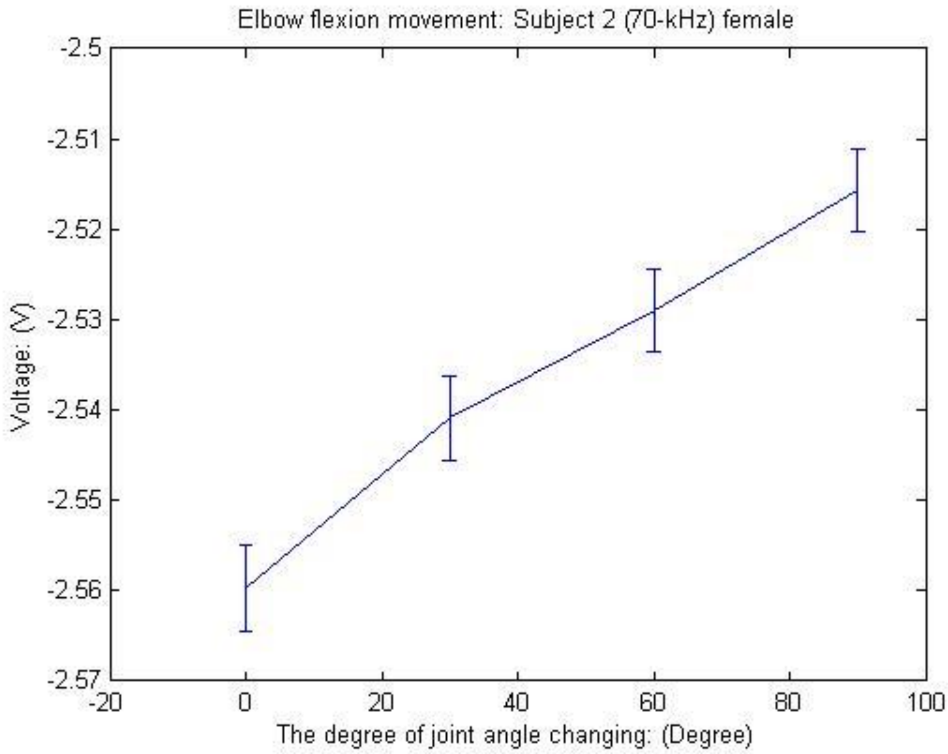


Fig. 33 The result of flexion movement in 70-kHz from female subject 2

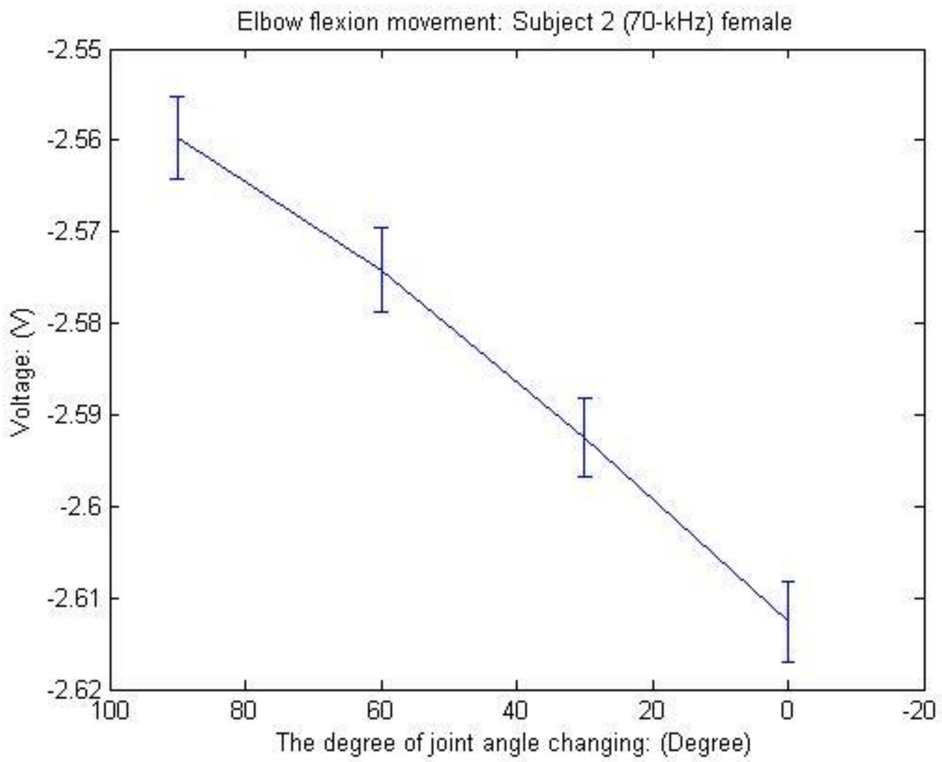


Fig. 34 The result of extension movement in 70-kHz from female subject 2

4.6.5 Conclusion of Multi-Subject Bio-impedance analyze with elbow joint angle measurement (70-kHz)

The result of multi-subject experiment has relative stable result in each subject whatever female or male subjects. Due to different subjects has different condition in weight, height, age, gender and fat percentage. The correlation result of each subject in 70-kHz condition as Table 3.

Table 3 The correlation result of each subject in 70-kHz condition with three electrode configurations

Subject No.(gender)	Configuration 1		Configuration 2		Configuration 3	
	Flexion	Extension	Flexion	Extension	Flexion	Extension
1(male)	0.987	-0.999	0.994	-0.985	0.981	-0.987
2(male)	0.991	-0.981	0.996	-0.997	0.999	-0.99
3(male)	0.997	-0.999	0.997	-0.953	0.997	-0.938
4(male)	0.987	-0.979	0.981	-0.975	0.99	-0.976
5(female)	0.995	-0.986	0.982	-0.981	0.999	-0.972
6(female)	0.995	-0.97	0.961	-0.992	0.985	-0.996
MEAN	0.992	-0.986	0.985	-0.981	0.992	-0.977
SD	0.004	0.011	0.013	0.014	0.007	0.019

4.7 Conclusion of correlation measurement

Chapter 7 is the conclusion for whole the result from participants. Due to the goal of this thesis is the evaluation of elbow joint movement using upper arm bio-impedance signal changing. Thus, there invites different gender, different body fat percentage participants to test the response. Fortunately, the experiment result in multi-subject condition is relative well. However, the number of participants is not enough to prove that this study is useful for the most of people. There are four frequencies, 20-kHz impedance signal is failing to evaluate the elbow joint movement in this study, and 45-kHz, 50-kHz and 70-kHz contribute relative high quality results.

4.8 Statistical analysis (Paired T-test)

The paired T-test is used to compared the mean of two populations when samples from the populations are available, in which each individual in one samples is paired with an individual in the other sample. In this method, the null hypothesis is that the mean difference is zero. i.e., $H_0: \mu_d = 0$.

The paired T-test is commonly used to test the following:

1. Statistical difference between two times points;
2. Statistical difference between two conditions;
3. Statistical difference between two measurements;
4. Statistical difference between a matched pair.

The Paired Samples t Test can only compare the means for two related paired on a continuous outcome that is normally distributed. The Paired Samples t Test is not appropriate for analyses involving the following:

1. unpaired data;
2. comparisons between more than two units/groups;
3. a continuous outcome that is not normally distributed;
4. an ordinal/ranked outcome.

The paired T-test statistical equation is the equation (40):

$$t = \frac{\overline{d} - (\mu_1 - \mu_2)}{S_d/\sqrt{n}} \tag{40}$$

Where $\overline{d}$ is the mean difference between the paired samples and S_d is the standard deviation of the differences d_i and n which is the number of pairs.

The step of two samples paired T-test is that these has a null hypothesis, which proposed the mean difference is zero between each samples. Thus, $\mu_1 - \mu_2 = 0$ in this condition. Then, paired T-test equation becomes the equation (41):

$$t = \frac{\overline{d} - 0}{S_d/\sqrt{n}} = \frac{\overline{d}}{S_d/\sqrt{n}} \tag{41}$$

After the calculation, paired-test method compares whether the mean difference is zero. Then check the p value table, where p value corresponding to the given test statistic t, which is shown as Sig.(2-tailed) in the table of output of paired T-test in SPSS. There would set a significance level α and compare it with p value. If p value is less than α value, the null hypothesis is false. Otherwise, the null hypothesis is true. The significance level α is 0.05 in this study.

This study apply paired T-test to check that whether the electrode configuration has influence on the correlation between upper arm bio-impedance changing and elbow joint angle changing.

4.8.1 The paired T-test for three electrode configurations

There are three electrode on the upper arm to evaluate the bio-impedance changing with elbow joint movement. According to the correlation result from chapter.7, all of the correlation calculation contributes high quality results. This chapter apply paired T-test to validate that whether electrode configurations has different influence on bio-impedance changing. All the data has been checked the normal distribution test. This study apply SPSS to produce paired T-test result. The paired T-test result presents three tables: The first table is ‘Paired samples statistics’, which shows the mean value, sample number, standard deviation and standard deviation error mean. The second table is ‘Paired samples correlations’, which calculates the correlation between each configurations and significant level of the correlation, if the significant level is higher or lower than 0.05, which means that the result from two electrode configurations has or has no correlation with each other. The third table shows the p value of null hypothesis, if the significance level is lower than 0.05, which means that two electrode configurations causes difference on the measurement of bio-impedance.

4.8.1.1 Male subject

4.8.1.1.1 First subject

The paired T-test result shows there has difference of the bio-impedance evaluation on the upper arm of subject 1 from three electrode configurations with elbow flexion and extension as shown in Fig. 34 and 35. There are three table in each figure. We could find there has difference in the first table, due to the different bio-impedance in different area. Both of table 2 in Fig.34 and 35 shows there are high correlation between each result from different configurations and the significant level is smaller than 0.05, it means that although different electrode configuration which is correspond to different cross-sectional area causes different bio-impedance measurement, however, each electrode configurations is not so far away from others and the difference is not large enough. Both of table 3 in Fig. 34 and 35 shows although the table 2 shows the difference is not large enough, but each electrode configurations has different influence on bio-impedance measurement, the p value from different electrode configurations is 0.000, 0.000 and 0.000 in flexion movement as shown in Fig. 34 and 0.000, 0.000 and 0.000 in extension as shown in Fig. 35. The reason could be found in table 1 in Fig. 34 and 35, there has different mean value.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.2273	4	.01779	.00889
	Configuration2	-2.8428	4	.01675	.00838
Pair 2	Configuration1	-2.2273	4	.01779	.00889
	Configuration3	-2.4197	4	.01528	.00764
Pair 3	Configuration2	-2.8428	4	.01675	.00838
	Configuration3	-2.4197	4	.01528	.00764

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.979	.021
Pair 2	Configuration1 & Configuration3	4	.951	.049
Pair 3	Configuration2 & Configuration3	4	.994	.006

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Configuration1 - Configuration2	.61555	.00366	.00183	.60972	.62138	336.006	3	.000
Pair 2	Configuration1 - Configuration3	.19236	.00573	.00286	.18324	.20148	67.142	3	.000
Pair 3	Configuration2 - Configuration3	-.42319	.00229	.00115	-.42683	-.41954	-369.412	3	.000

Fig. 35 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 1(male)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.1819	4	.01618	.00809
	Configuration2	-2.6728	4	.01755	.00877
Pair 2	Configuration1	-2.1819	4	.01618	.00809
	Configuration3	-2.4226	4	.01244	.00622
Pair 3	Configuration2	-2.6728	4	.01755	.00877
	Configuration3	-2.4226	4	.01244	.00622

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.986	.014
Pair 2	Configuration1 & Configuration3	4	.993	.007
Pair 3	Configuration2 & Configuration3	4	.995	.005

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Configuration1 - Configuration2	.49083	.00316	.00158	.48579	.49586	310.386	3	.000
Pair 2	Configuration1 - Configuration3	.24063	.00410	.00205	.23409	.24716	117.242	3	.000
Pair 3	Configuration2 - Configuration3	-.25020	.00532	.00266	-.25867	-.24173	-93.976	3	.000

Fig. 36 The comparison between the differences of three electrode configurations with elbow extension movement in SPSS from subject 1(male).

4.8.1.1.2 Second subject

The paired T-test result shows there has difference of the bio-impedance evaluation on the upper arm of subject 2 from three electrode configurations with elbow flexion and extension as shown in Fig. 36 and 37. The reason is same as first subject in chapter. 8.1.1.1. Both of table 1 in Fig. 36 and 37 shows that each electrode configurations causes different mean value of bio-impedance evaluation. Both of table 2 in Fig. 36 and 37 shows there has high correlation of bio-impedance evaluation from each electrode configurations. Both of table 3 in Fig.36 and 37 shows the p value is smaller than 0.05, which is 0.000, 0.003 and 0.000 from the elbow flexion movement as shown in Fig. 36 and 0.000, 0.001 and 0.000 from elbow extension movement as shown in Fig. 37. Thus, different electrode configurations contributes different bio-impedance evaluations.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.6414	4	.00833	.00417
	Configuration2	-2.3675	4	.03817	.01909
Pair 2	Configuration1	-2.6414	4	.00833	.00417
	Configuration3	-2.5994	4	.01732	.00866
Pair 3	Configuration2	-2.3675	4	.03817	.01909
	Configuration3	-2.5994	4	.01732	.00866

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.977	.023
Pair 2	Configuration1 & Configuration3	4	.996	.004
Pair 3	Configuration2 & Configuration3	4	.992	.008

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Configuration1 - Configuration2	-.27391	.03008	.01504	-.32179	-.22604	-18.210	3	.000
Pair 2	Configuration1 - Configuration3	-.04201	.00905	.00453	-.05642	-.02760	-9.279	3	.003
Pair 3	Configuration2 - Configuration3	.23191	.02109	.01055	.19834	.26547	21.987	3	.000

Fig. 37 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 2(male).

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.5574	4	.00481	.00241
	Configuration2	-2.3243	4	.02922	.01461
Pair 2	Configuration1	-2.5574	4	.00481	.00241
	Configuration3	-2.5346	4	.00851	.00426
Pair 3	Configuration2	-2.3243	4	.02922	.01461
	Configuration3	-2.5346	4	.00851	.00426

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.978	.022
Pair 2	Configuration1 & Configuration3	4	.985	.015
Pair 3	Configuration2 & Configuration3	4	.999	.001

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Configuration1 - Configuration2	-.23314	.02453	.01227	-.27217	-.19410	-19.007	3	.000
Pair 2	Configuration1 - Configuration3	-.02284	.00386	.00193	-.02898	-.01670	-11.834	3	.001
Pair 3	Configuration2 - Configuration3	.21030	.02073	.01036	.17732	.24328	20.293	3	.000

Fig. 38 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 2(male).

4.8.1.1.3 Third subject

The paired T-test result shows there has difference of the bio-impedance evaluation on the upper arm of subject 3 from three electrode configurations with elbow flexion and extension as shown in Fig. 38 and 39. Both of table 1 in Fig. 38 and 39 shows that each electrode configurations causes different mean value of bio-impedance evaluation. Both of table 2 in Fig. 38 and 39 shows there has high correlation of bio-impedance evaluation from each electrode configurations. Both of table 3 in Fig.38 and 39 shows the p value is smaller than 0.05, which is 0.000, 0.000 and 0.001 from the elbow flexion movement as shown in Fig. 38 and 0.000, 0.000 and 0.002 from elbow extension movement as shown in Fig. 39. Thus, different electrode configurations contributes different bio-impedance evaluations.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.4104	4	.01129	.00565
	Configuration2	-2.6367	4	.02543	.01271
Pair 2	Configuration1	-2.4104	4	.01129	.00565
	Configuration3	-2.5682	4	.01341	.00671
Pair 3	Configuration2	-2.6367	4	.02543	.01271
	Configuration3	-2.5682	4	.01341	.00671

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.998	.002
Pair 2	Configuration1 & Configuration3	4	.992	.008
Pair 3	Configuration2 & Configuration3	4	.996	.004

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Configuration1 - Configuration2	.22629	.01417	.00709	.20374	.24885	31.935	3	.000
Pair 2	Configuration1 - Configuration3	.15774	.00261	.00130	.15359	.16189	121.023	3	.000
Pair 3	Configuration2 - Configuration3	-.06856	.01213	.00607	-.08786	-.04925	-11.300	3	.001

Fig. 39 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 3(male).

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.3871	4	.01303	.00652
	Configuration2	-2.6227	4	.01720	.00860
Pair 2	Configuration1	-2.3871	4	.01303	.00652
	Configuration3	-2.5686	4	.00932	.00466
Pair 3	Configuration2	-2.6227	4	.01720	.00860
	Configuration3	-2.5686	4	.00932	.00466

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.946	.054
Pair 2	Configuration1 & Configuration3	4	.941	.059
Pair 3	Configuration2 & Configuration3	4	.789	.211

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Configuration1 - Configuration2	.23559	.00644	.00322	.22535	.24584	73.168	3	.000
Pair 2	Configuration1 - Configuration3	.18152	.00531	.00265	.17308	.18996	68.429	3	.000
Pair 3	Configuration2 - Configuration3	-.05408	.01139	.00570	-.07220	-.03595	-9.495	3	.002

Fig. 40 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 3(male).

4.8.1.1.4 Fourth subject

The paired T-test result shows there has difference of the bio-impedance evaluation on the upper arm of subject 4 from three electrode configurations with elbow flexion and extension as shown in Fig. 40 and 41. Both of table 1 in Fig. 40 and 41 shows that each electrode configurations causes different mean value of bio-impedance evaluation. Both of table 2 in Fig. 40 and 41 shows there has high correlation of bio-impedance evaluation from each electrode configurations. Both of table 3 in Fig. 40 and 41 shows the p value is smaller than 0.05, which is 0.001, 0.000 and 0.003 from the elbow flexion movement as shown in Fig. 40 and 0.000, 0.000 and 0.005 from elbow extension movement as shown in Fig. 41. Thus, different electrode configurations contributes different bio-impedance evaluations.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.2636	4	.00840	.00420
	Configuration2	-2.3390	4	.01862	.00931
Pair 2	Configuration1	-2.2636	4	.00840	.00420
	Configuration3	-2.3629	4	.01833	.00917
Pair 3	Configuration2	-2.3390	4	.01862	.00931
	Configuration3	-2.3629	4	.01833	.00917

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.950	.050
Pair 2	Configuration1 & Configuration3	4	1.000	.000
Pair 3	Configuration2 & Configuration3	4	.957	.043

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Configuration1 - Configuration2	.07542	.01097	.00548	.05797	.09287	13.754	3	.001
Pair 2	Configuration1 - Configuration3	.09928	.00993	.00497	.08347	.11509	19.988	3	.000
Pair 3	Configuration2 - Configuration3	.02386	.00544	.00272	.01521	.03252	8.771	3	.003

Fig. 41 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 4(male).

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.2356	4	.00749	.00374
	Configuration2	-2.3095	4	.01265	.00633
Pair 2	Configuration1	-2.2356	4	.00749	.00374
	Configuration3	-2.3299	4	.01328	.00664
Pair 3	Configuration2	-2.3095	4	.01265	.00633
	Configuration3	-2.3299	4	.01328	.00664

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.943	.057
Pair 2	Configuration1 & Configuration3	4	.991	.009
Pair 3	Configuration2 & Configuration3	4	.909	.091

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Configuration1 - Configuration2	.07392	.00612	.00306	.06419	.08365	24.175	3	.000
Pair 2	Configuration1 - Configuration3	.09429	.00594	.00297	.08483	.10374	31.729	3	.000
Pair 3	Configuration2 - Configuration3	.02037	.00557	.00278	.01151	.02922	7.320	3	.005

Fig. 42 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 4(male).

4.8.1.2 Female subject

4.8.1.2.1 First subject

The paired T-test result shows there has difference of the bio-impedance evaluation on the upper arm of subject 1 from three electrode configurations with elbow flexion and extension as shown in Fig. 42 and 43. Both of table 1 in Fig. 42 and 43 shows that each electrode configurations causes different mean value of bio-impedance evaluation. Both of table 2 in Fig. 42 and 43 shows there has high correlation of bio-impedance evaluation from each electrode configurations. Both of table 3 in Fig. 42 and 43 shows the p value is smaller than 0.05, which is 0.000, 0.000 and 0.000 from the elbow flexion movement as shown in Fig. 42 and 0.000, 0.000 and 0.000 from elbow extension movement as shown in Fig. 43. Thus, different electrode configurations contributes different bio-impedance evaluations.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.5567	4	.01494	.00747
	Configuration2	-2.5928	4	.01640	.00820
Pair 2	Configuration1	-2.5567	4	.01494	.00747
	Configuration3	-2.7973	4	.02176	.01088
Pair 3	Configuration2	-2.5928	4	.01640	.00820
	Configuration3	-2.7973	4	.02176	.01088

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.992	.008
Pair 2	Configuration1 & Configuration3	4	.998	.002
Pair 3	Configuration2 & Configuration3	4	.983	.017

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Configuration1 - Configuration2	.03613	.00247	.00123	.03221	.04005	29.313	3	.000
Pair 2	Configuration1 - Configuration3	.24060	.00690	.00345	.22962	.25158	69.747	3	.000
Pair 3	Configuration2 - Configuration3	.20447	.00639	.00320	.19430	.21465	63.950	3	.000

Fig. 43 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 1(female).

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.4993	4	.01319	.00660
	Configuration2	-2.5893	4	.01332	.00666
Pair 2	Configuration1	-2.4993	4	.01319	.00660
	Configuration3	-2.7862	4	.01623	.00811
Pair 3	Configuration2	-2.5893	4	.01332	.00666
	Configuration3	-2.7862	4	.01623	.00811

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.996	.004
Pair 2	Configuration1 & Configuration3	4	.998	.002
Pair 3	Configuration2 & Configuration3	4	.997	.003

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Configuration1 - Configuration2	.08994	.00112	.00056	.08815	.09172	160.544	3	.000
Pair 2	Configuration1 - Configuration3	.28686	.00315	.00157	.28186	.29187	182.245	3	.000
Pair 3	Configuration2 - Configuration3	.19693	.00312	.00156	.19197	.20189	126.292	3	.000

Fig. 44 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 1(female).

4.8.1.2.2 Second subject

The paired T-test result shows there has difference of the bio-impedance evaluation on the upper arm of subject 1 from three electrode configurations with elbow flexion and extension as shown in Fig. 44 and 45. Both of table 1 in Fig. 44 and 45 shows that each electrode configurations causes different mean value of bio-impedance evaluation. Both of table 2 in Fig. 44 and 45 shows there has high correlation of bio-impedance evaluation from each electrode configurations. Both of table 3 in Fig. 44 and 45 shows the p value is smaller than 0.05, which is 0.001, 0.000 and 0.000 from the elbow flexion movement as shown in Fig. 44 and 0.000, 0.001 and 0.058 from elbow extension movement as shown in Fig. 45. Thus, electrode configuration1 contributes different bio-impedance evaluations, but the result between electrode configuration 2 and 3 is similar due to its p value is 0.058.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.5363	4	.01867	.00933
	Configuration2	-2.5778	4	.02487	.01243
Pair 2	Configuration1	-2.5363	4	.01867	.00933
	Configuration3	-2.6452	4	.02926	.01463
Pair 3	Configuration2	-2.5778	4	.02487	.01243
	Configuration3	-2.6452	4	.02926	.01463

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.984	.016
Pair 2	Configuration1 & Configuration3	4	.993	.007
Pair 3	Configuration2 & Configuration3	4	.995	.005

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Configuration1 - Configuration2	.04150	.00731	.00366	.02986	.05314	11.348	3	.001
Pair 2	Configuration1 - Configuration3	.10888	.01096	.00548	.09144	.12631	19.875	3	.000
Pair 3	Configuration2 - Configuration3	.06738	.00522	.00261	.05908	.07568	25.830	3	.000

Fig. 45 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 2(female).

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Configuration1	-2.5069	4	.01710	.00855
	Configuration2	-2.5783	4	.02467	.01233
Pair 2	Configuration1	-2.5069	4	.01710	.00855
	Configuration3	-2.5562	4	.00990	.00495
Pair 3	Configuration2	-2.5783	4	.02467	.01233
	Configuration3	-2.5562	4	.00990	.00495

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Configuration1 & Configuration2	4	.990	.010
Pair 2	Configuration1 & Configuration3	4	.981	.019
Pair 3	Configuration2 & Configuration3	4	.998	.002

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Configuration1 - Configuration2	.07148	.00809	.00404	.05860	.08435	17.670	3	.000
Pair 2	Configuration1 - Configuration3	.04938	.00762	.00381	.03726	.06151	12.961	3	.001
Pair 3	Configuration2 - Configuration3	-.02210	.01480	.00740	-.04564	.00145	-2.987	3	.058

Fig. 46 The comparison between the differences of three electrode configurations with elbow flexion movement in SPSS from subject 2(female).

4.8.1.3 Conclusion for paired T-test for three electrode configurations

Chapter 8.1 is about paired T-test for three electrode configurations from six subjects. The SPSS generates three tables for each motion and subjects. Except for second female subject, other subjects contributes similar result which mean that each electrode configurations on other subjects has different influence on bio-impedance evaluation. The electrode configuration 2 and 3 on second female subject contributes similar result, but other electrode configurations are different.

4.8.2 Analysis the mean of mean data using paired T-test

We could know the stages of motion consists of 4 step from the chapter of multi-subject. Due to the window size for each stage is 1000 samples and this study consists of 4 stages. Thus, six subjects totally has 6000 samples for 1 stages and 24000 samples for 4 stages. Chapter 8.2 calculate the mean of 6000 samples from each stages. Then, this study compares the mean value which is from the mean of mean data using paired T-test to check whether the electrode configuration caused difference. The output of paired T-test using the mean of mean data shows there has difference between each electrode configurations. The Fig.46 and 47 show the paired T-test output of elbow flexion and extension using the mean of mean data of six subjects.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	configuration1 - configuration2	.263750	.004383	.002192	.256775	.270725	120.344	3	.000
Pair 2	configuration1 - configuration3	.175417	.000833	.000417	.174091	.176743	421.000	3	.000
Pair 3	configuration2 - configuration3	-.088333	.004714	.002357	-.095834	-.080832	-37.477	3	.000

Fig.47 The paired T-test output of elbow flexion using the mean of mean data.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	configuration1 - configuration2	.120417	.010035	.005017	.104449	.136384	24.000	3	.000
Pair 2	configuration1 - configuration3	.125833	.006161	.003081	.116029	.135638	40.846	3	.000
Pair 3	configuration2 - configuration3	.005417	.004167	.002083	-.001213	.012047	2.600	3	.080

Fig.48 The paired T-test output of elbow extension using the mean of mean data.

4.8.2.1 The test of the influence from gender to measurement using paired T-test

According to Chapter 8.2. There has difference which is caused by different electrode configurations in multi-subject condition. This chapter validates whether the gender has influence on measurement using three electrode configurations. Thus, this chapter separates the gender and tests the influence from three electrode configurations to measurement. The result shows three electrode configurations caused the different result whatever the gender of subjects is. Thus, the gender of subjects has no influence on the measurement. The Fig.48 and 49 show the paired T-test output of elbow flexion and extension using the mean of mean data of male and female.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	config1M - config1F	.133125	.055429	.027715	.044925	.221325	4.803	3	.017
Pair 2	config2M - config2F	.186250	.024622	.012311	.147071	.225429	15.129	3	.001
Pair 3	config3M - config3F	.213750	.039291	.019645	.151230	.276270	10.880	3	.002

Fig. 49 The paired T-test output of elbow flexion using the mean of mean data of male and female. Where M is male, F is female.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	config1M - config1F	.245000	.012416	.006208	.225243	.264757	39.464	3	.000
Pair 2	config2M - config2F	.060625	.006250	.003125	.050680	.070570	19.400	3	.000
Pair 3	config3M - config3F	.236875	.008004	.004002	.224139	.249611	59.190	3	.000

Fig. 50 The paired T-test output of elbow extension using the mean of mean data of male and female. Where M is male, F is female.

4.8.2.2 The test of the influence from fat percentage to measurement using paired T-test

This chapter separates the fat and thin subjects and tests the influence from three electrode configurations for measurement. The results show that fat and thin subjects contribute different result from three electrode configurations. However, the limitation is that only two subjects has been made the comparison in this chapter. The Fig.50 and 51 show the paired T-test output of elbow flexion and extension using the mean of mean data from fat and thin subjects.

flexsion compare Subject3 Fat 17.9(T) & Subject 5 Fat 37.6% (F)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	configuration1T - configuration1F	.14500	.00577	.00289	.13581	.15419	50.229	3	.000
Pair 2	configuration2T - configuration2F	-.04250	.01500	.00750	-.06637	-.01863	-5.667	3	.011
Pair 3	configuration3T - configuration3F	.23250	.00957	.00479	.21727	.24773	48.568	3	.000

Fig. 51 The paired T-test output of elbow flexion using the mean of mean data from fat and thin subjects. Where T is thin, F is fat.

Extension compare Subject3 Fat 17.9(T) & Subject 5 Fat 37.6% (F)

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	configuration1T - configuration1F	.11500	.00577	.00289	.10581	.12419	39.837	3	.000
Pair 2	configuration2T - configuration2F	-.03500	.01291	.00645	-.05554	-.01446	-5.422	3	.012
Pair 3	configuration3T - configuration3F	.21750	.00957	.00479	.20227	.23273	45.434	3	.000

Fig. 52 The paired T-test output of elbow extension using the mean of mean data from fat and thin subjects. Where T is thin, F is fat.

Chapter 5
Conclusion and discussion

5.1 Conclusion and discussion

This study is composed by three experiments. This first one is the preliminary experiment which evaluates 9 stages of the elbow joint motion using 45-kHz bio-impedance signal, it contributes high correlation but high standard deviation response. Four limitations has been found in the preliminary experiment. The first of them is only one subject. The second limitation is there has only one frequency. The third limitation is due to the result has high standard deviation. The fourth limitation is there has no concern of the influence of body parameter on the measurement. Thus, the second experiment evaluates 4 stages of the elbow joint movement using three frequency bio-impedance signal. Three frequency consists of 20-kHz, 50-kHz and 70-kHz in the second experiment. The results shows that 20-kHz bio-impedance is not suitable in this experiment condition. 50-kHz and 70-kHz bio-impedance signal is useful to evaluate the elbow joint motion. The best evaluation of 4 stages of the elbow flexion motion is using 50-kHz bio-impedance signal on the first electrode configuration, and the best evaluation of 4 stages of the elbow extension motion is using 70-kHz bio-impedance signal on the first electrode configuration. Moreover, the best correlation between elbow flexion motion and bio-impedance signal is 0.998 in the second experiment, the best correlation between elbow extension motion and bio-impedance signal is -0.999 in the second experiment. The third experiment has six subjects, two female and four male subjects join the experiment. All the subjects contributes high quality result in 70-kHz condition. In this experiment, this study separates subjects into different group, such as gender and fat percentage. The last part of this study is statistical analysis to check whether the electrode configuration has influence on the correlation between elbow joint motion and 70-kHz bio-impedance signal. If the output of paired T-test t corresponding to p-value is less than the significance level α which is equal to 0.05, two samples in paired T-test are different with statistical coefficient. According to the paired T-test using six subjects data and the mean of mean data, it shows that different electrode configurations has influence on the correlation between elbow joint motion and 70-kHz bio-impedance signal. Moreover, the paired T-test result using the mean of mean data shows different electrode configurations contributes different result in the condition of whole subjects, different gender and different fat percentage condition.

References

[1] Maurice LeBlanc, MSME, CP "Give Hope - Give a Hand" - The LN-Prosthetic Hand
[2] S. B. Rutkove, “Electrical impedance myography: Background, current state, and future directions,” Muscle Nerve, vol. 40, no. 6, pp. 936–946, 2009.
[3] M. Adrian and J. M. Cooper, The biomechanics of human movement. Benchmark Press, 1995.
[4] B.C:Elliott, Sports hedicine, 6, pp. 285-294; 1988.
[5] D. Novak, X. Omlin, R. Leins-Hess, and R. Riener, “Predicting targets of human reaching motions using different sensing technologies,” Biomedical Engineering, IEEE Transactions on, vol. 60, no. 9, pp. 2645 2654, 2013.
[6] T. A. Kuiken, G. Li, B. A. Lock, R. D. Lipschutz, L. A. Miller, K. A. Stubblefield, and K. B. Englehart, “Targeted muscle reinnervation for real-time myoelectric control of multifunction artificial arms,” Jama, vol. 301, no. 6, pp. 619–628, 2009.
[7] J. C. Kim, S. C. Kim, K. C. Nam, S. H. Ahn, M. Park, and D. W. Kim, “Evaluation of a bio-impedance method for measuring human arm movement,” Yonsei medical journal, vol. 43, no. 5, pp. 637–643, 2002.
[8] C. S. L. Tsui, P. Jia, J. Q. Gan, H. Hu, and K. Yuan, “EMG-based hands-free wheelchair control with EOG attention shift detection,” in Robotics and Biomimetics, 2007. ROBIO 2007. IEEE International Conference on, 2007, pp. 1266–1271.
[9] I. Moon, M. Lee, and M. Mun, “A novel EMG-based human-computer interface for persons with disability,” in Mechatronics, 2004. ICM’04. Proceedings of the IEEE International Conference on, 2004, pp. 519–524.
[10] Mr. Huang Yun fei “Development of a Bioimpedance Based Human Machine Interface ” M.S. thesis, Prince of Songkla University, Thailand, 2009.
[11] K. R. Foster and H. C. Lukaski, “Whole-body impedance–what does it measure?” The American journal of clinical nutrition, vol. 64, no. 3, p. 388S–396S, 1996.
[12] U. G. Kyle, I. Bosaeus, A. D. De Lorenzo, P. Deurenberg, M. Elia, J. M. Gómez, B. L. Heitmann, L. Kent-Smith, J.-C. Melchior, M. Pirlich, and others, “Bioelectrical impedance analysis—part I: review of principles and methods,” Clinical nutrition, vol. 23, no. 5, pp. 1226–1243, 2004.
[13] S. F. Khalil, M. S. Mohktar, and F. Ibrahim, “The theory and fundamentals of bioimpedance analysis in clinical status monitoring and diagnosis of diseases,” Sensors, vol. 14, no. 6, pp. 10895–10928, 2014.
[14] L. C. Ward, J. M. Dyer, N. M. Byrne, K. K. Sharpe, and A. P. Hills, “Validation of a three-frequency bioimpedance spectroscopic method for body composition analysis,” Nutrition, vol. 23, no. 9, pp. 657–664, 2007.
[15] R. Gudivaka, D. A. Schoeller, R. F. Kushner, and M. J. G. Bolt, “Single-and multifrequency models for bioelectrical impedance analysis of body water compartments,” Journal of Applied Physiology, vol. 87, no. 3, pp. 1087–1096, 1999.
[16] M. G. Rikkert, P. Deurenberg, R. W. Jansen, M. A. Hof, and W. H. Hoefnagels, “Validation of multi-frequency bioelectrical impedance analysis in detecting changes in fluid balance of geriatric patients,” Journal of the American Geriatrics Society, vol. 45, no. 11, pp. 1345–1351, 1997.
[17] G. Woodrow, B. Oldroyd, J. H. Turney, P. S. Davies, J. M. Day, and M. A. Smith, “Measurement of total body water by bioelectrical impedance in chronic renal failure.,” European journal of clinical nutrition, vol. 50, no. 10, pp. 676–681, 1996.
[18] M. Y. Jaffrin and H. Morel, “Body fluid volumes measurements by impedance: A review of bioimpedance spectroscopy (BIS) and bioimpedance analysis (BIA) methods,” Medical engineering & physics, vol. 30, no. 10, pp. 1257–1269, 2008.
[19] R. N. Pierson, J. Wang, E. W. Colt, and P. Neumann, “Body composition measurements in normal man: the potassium, sodium, sulfate and tritium spaces in 58 adults,” Journal of chronic diseases, vol. 35, no. 6, pp. 419–428, 1982.
[20] B. H. Cornish, L. C. Ward, B. J. Thomas, S. A. Jebb, and M. Elia, “Evaluation of multiple frequency bioelectrical impedance and Cole-Cole analysis for the assessment of body water volumes in healthy humans.,” European journal of clinical nutrition, vol. 50, no. 3, pp. 159–164, 1996.
[21] D. A. Schoeller, “Bioelectrical impedance analysis What does it measure?,” Annals of the New York Academy of sciences, vol. 904, no. 1, pp. 159–162, 2000.
[22] P. L. Cox-Reijven and P. B. Soeters, “Validation of bio-impedance spectroscopy: effects of degree of obesity and ways of calculating volumes from measured resistance values,” International journal of

obesity, vol. 24, no. 3, p. 271, 2000.
[23] W. J. Hannan, S. J. Cowen, C. Plester, and K. C. H. Fearon, “Proximal and distal measurements of extracellular and total body water by multi-frequency bio-impedance analysis in surgical patients,” Applied radiation and isotopes, vol. 49, no. 5–6, pp. 621–622, 1998.
[24] C. P. Earthman, J. R. Matthie, P. M. Reid, I. T. Harper, E. Ravussin, and W. H. Howell, “A comparison of bioimpedance methods for detection of body cell mass change in HIV infection,” Journal of Applied Physiology, vol. 88, no. 3, pp. 944–956, 2000.
[25] L. T. Ho, R. F. Kushner, D. A. Schoeller, R. Gudivaka, and D. M. Spiegel, “Bioimpedance analysis of total body water in hemodialysis patients,” Kidney international, vol. 46, no. 5, pp. 1438–1442, 1994.
[26] E. M. Baarends, W. V. M. Lichtenbelt, E. F. M. Wouters, and A. Schols, “Body-water compartments measured by bio-electrical impedance spectroscopy in patients with chronic obstructive pulmonary disease,” Clinical Nutrition, vol. 17, no. 1, pp. 15–22, 1998.
[27] R. Gudivaka, D. A. Schoeller, R. F. Kushner, and M. J. G. Bolt, “Single-and multifrequency models for bioelectrical impedance analysis of body water compartments,” Journal of Applied Physiology, vol. 87, no. 3, pp. 1087–1096, 1999.
[28] H. C. Lukaski, W. W. Bolonchuk, C. B. Hall, and W. A. Siders, “Validation of tetrapolar bioelectrical impedance method to assess human body composition,” Journal of applied physiology, vol. 60, no. 4, pp. 1327–1332, 1986.
[29] X. Xie, N. Kolthoff, O. Bärenholt, and S. P. Nielsen, “Validation of a leg-to-leg bioimpedance analysis system in assessing body composition in postmenopausal women,” International journal of obesity, vol. 23, no. 10, pp. 1079–1084, 1999.
[30] Prentice, “Evaluation of the novel Tanita body-fat analyser to measure body composition by comparison with a four-compartment model,” British Journal of Nutrition, vol. 83, no. 02, pp. 115–122, 2000.
[31] A. C. Utter, D. C. Nieman, A. N. Ward, and D. E. Butterworth, “Use of the leg-to-leg bioelectrical impedance method in assessing body-composition change in obese women,” The American journal of clinical nutrition, vol. 69, no. 4, pp. 603–607, 1999.
[32]P. Deurenberg and M. Deurenberg-Yap, “Validation of skinfold thickness and hand-held impedance measurements for estimation of body fat percentage among singaporean chinese, malay and indian subjects,” Asia Pacific journal of clinical nutrition, vol. 11, no. 1, pp. 1–7, 2002.
[33] S. Ghosh, D. Meister, S. Cowen, J. W. Hannan, and A. Ferguson, “Body composition at the bedside.,” European journal of gastroenterology & hepatology, vol. 9, no. 8, pp. 783–788, 1997.
[34] A. C. Buchholz, C. Bartok, and D. A. Schoeller, “The validity of bioelectrical impedance models in clinical populations,” Nutrition in Clinical Practice, vol. 19, no. 5, pp. 433–446, 2004.
[35] N. I. Tanaka, M. Miyatani, Y. Masuo, T. Fukunaga, and H. Kanehisa, “Applicability of a segmental bioelectrical impedance analysis for predicting the whole body skeletal muscle volume,” Journal of Applied Physiology, vol. 103, no. 5, pp. 1688–1695, 2007.
[36] B. J. Thomas, B. H. Cornish, M. J. Pattemore, M. Jacobs, and L. C. Ward, “A comparison of the whole-body and segmental methodologies of bioimpedance analysis,” Acta diabetologica, vol. 40, no. 1, pp. s236–s237, 2003.
[37] R. N. Baumgartner, W. C. Chumlea, and A. F. Roche, “Bioelectric impedance phase angle and body composition.,” The American journal of clinical nutrition, vol. 48, no. 1, pp. 16–23, 1988.
[38] B. J. Thomas, B. H. Cornish, L. C. Ward, and M. A. Patterson, “A comparison of segmental and wrist-to-ankle methodologies of bioimpedance analysis,” Applied radiation and isotopes, vol. 49, no. 5–6, pp. 477–478, 1998.
[39] H. Scharfetter, M. Monif, Z. László, T. Lambauer, H. Hutten, and H. Hinghofer-Szalkay, “Effect of postural changes on the reliability of volume estimations from bioimpedance spectroscopy data,” Kidney international, vol. 51, no. 4, pp. 1078–1087, 1997.
[40] U. G. Kyle, L. Genton, L. Karsegard, D. O. Slosman, and C. Pichard, “Single prediction equation for bioelectrical impedance analysis in adults aged 20–94 years,” Nutrition, vol. 17, no. 3, pp. 248–253, 2001.
[41] S. S. Sun et al., “Development of bioelectrical impedance analysis prediction equations for body composition with the use of a multicomponent model for use in epidemiologic surveys,” The American journal of clinical nutrition, vol. 77, no. 2, pp. 331–340, 2003.
[42] S. C. Kim, K. C. Nam, D. W. Kim, C. Y. Ryu, Y. H. Kim, and J. C. Kim, “Optimum electrode

configuration for detection of arm movement using bio-impedance," Medical and Biological Engineering and Computing, vol. 41, no. 2, pp. 141–145, 2003.
[43] E. Mylott, E. Kutschera, and R. Widenhorn, "Bioelectrical impedance analysis as a laboratory activity: At the interface of physics and the body," American Journal of Physics, vol. 82, no. 5, pp. 521–528, 2014.

VITAE

Name Mr. RenHe Liu

Student ID 5710120006

Educational Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Engineering (Electrical Engineering)	Electrical Engineering	2014

List of Publication and Proceeding

1. RenHe Liu, Booncharoen Wongkittisuksa, "The investigation of joint angle movement using bio-impedance method," International Conference on "Engineering & Technology, Computer , Basic & Applied Sciences" (ECBA- 2017), 2017.

2. RenHe Liu, Booncharoen Wongkittisuksa, "The study of arm joint angle movement using one-channel and multi-frequency bio-impedance measurement," The 2017 International Electrical Engineering Congress (iEECON2017), 2017.

3. RenHe Liu, Booncharoen Wongkittisuksa, "The evaluation of arm joint angle movement using multi-frequency and multi-subject bio-impedance measurement," ECTI-CON 2017, 2017.