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The study of arm joint angle movement using one-channel and multi-frequency bio-impedance measurement

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***Abstract*—This article presents the dynamic parameter evaluation of elbow joint angle movement using one channel bio-impedance measurement which works with a goniometer. The multi-frequencies consists of 20-kHz, 50-kHz and 70-kHz is investigated. The bio-impedance measurement system consists of Wein oscillator, Howland constant current source, high-pass filter, instrument amplifier, rectifier, low-pass filter, coupling circuit and amplifier. The correlation between arm impedance changing and elbow joint angle changing was calculated. The motion of elbow joint angle movement consists of 4 stage in this case. The elbow flexion motion start at 0 degree, and the subject lifts the arm 30 degree per time until the motion achieve 90 degree. The elbow extension motion as the opposite condition with elbow flexion motion. All the motion for each frequency were repeated three times. Three electrode configuration were applied in this article. The comparison between each electrode configuration is used to validate the influence of different frequency of injected constant current. All the motion for each electrode configuration repeated three times. The result show there has high correlation between bio-impedance changing and elbow joint angle movement in 50-kHz and 70-kHz condition. The result of flexion motion (50-kHZ) in each electrode configuration condition is 0.998, 0.982 and 0.993, respectively. The result of extension motion (50-kHz) in each electrode configuration condition is -0.995, -0.966 and -0.983, respectively. 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. The result of 50-kHz condition and 70-kHz condition show high correlation between bio-impedance changing and elbow joint angle changing in each electrode configuration.**

Keywords*—Bio-impedance change; elbow joint angle movement; one-channel bio-impedance measurement; multi-frequency bio-impedance measurement.

I. Introduction

Electromyography (EMG) is the one of most popular method to analysis the arm movement. EMG signal is generated during muscles contraction, and has high accuracy of motion prediction [1]. However, EMG signal is short of dynamic parameter and hard to evaluate limb joint angle movement. Bio-impedance measurement is a non-invasive, high performance method, and useful for the evaluation of properties of human body rely on high-frequency, low-intensity current [2]. It is suitable to explain the kinetic parameter of movement [2, 3, 4,]. Some previous researcher evaluate the joint angle movement to solve the limitation of EMG using bio-impedance method [3]. Bio-impedance method consists of single frequency bio-impedance analysis (SF-BIA) and multi-frequency bio-impedance analysis (MF-BIA) [5, 6]. SF-BIA is generally at 50-kHz. Moreover, SF-BIA uses the location of electrodes on hand and foot, foot to foot and hand to hand, it is a weight of sum of extra-cellular water (ECW) and intra-cellular water (ICW). MF-BIA uses empirical linear regression models but includes impedances using multi-frequency (0, 1, 5, 50, 100, 200 to 500 kHz) [6]. A low performance of bio-impedance measurement from the frequency which is below 5-kHz or above 200-kHz. According to previous research, which evaluate the elbow and wrist joint angle movement using bio-impedance signal [2]. Moreover, this research team evaluate the influence from different electrode configurations to the evaluation of arm joint angle movement using bio-impedance signal and apply 50-kHz in their research [3]. This article presents a one-channel multi-frequency bio-impedance measurement to evaluate the elbow joint angle movement. The influence of three injected frequency to the correlation between bio-impedance changing and elbow joint angle changing was investigated. Three frequencies method consists of 20-kHz, 50-kHz and 70-kHz and three electrode configurations were applied in this study. The subject repeat the elbow flexion and extension movements three times for each frequencies and electrode configuration. The motion of elbow joint angle movement consists of 4 stage in this case. The elbow flexion motion start at 0 degree, and the subject lifts the arm 30 degree per time until the motion achieve 90 degree. The elbow extension motion as the opposite condition with elbow flexion motion.

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II. Theory

A. The basic concept of bio-impedanc

Impedance (Z) is the obstruction to electrical current, it is dependent on the frequency of the injected current, defined in impedance magnitude ($|Z|$) and phase angle (ϕ). Bio-impedance consists of resistance (R) which is caused by total body water and reactance (X_C) which is caused by the capacitance of the cell membrane [6].

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

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

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

The resistance (R) is affected by the length, surface area (A) and the resistivity (ρ) as equation (4) [7].

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

Different type of material cause different resistivity (ρ), and their value is related with frequency. Reactance (X_C) is caused by the capacitance of cell membrane [7]. It is affected by frequency of injected current and the capacitance of cell membrane as equation (5). [7]

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

Some previous work show different theory of bio-impedance method [8], they describe the bio-impedance basic concept using series-equivalent or parallel-equivalent model.

B. Multi-frequency bio-impedance analysis (MF-BIA)

MF-BIA is included at least two frequencies to analysis the response of bio-impedance measurement. MF-BIA is rely on the opinion which consider the ECW and TBW can be evaluated through the body segment was injected low and high frequencies electric current, respectively. Some previous research review previous different frequencies method to MF-BIA [5].

III. Materials And Methods

Three frequencies which consists of 20-kHz, 50-kHz and 70-kHz and three electrode configuration were applied in this study. The motion includes of elbow flexion and elbow extension. The elbow flexion motion start at 0 degree, and the subject lifts the arm 30 degree per time until the motion reach 90 degree. The elbow extension motion as the opposite condition with elbow flexion motion. One male subject bio-impedance was measured in this case, his weight is 80-kg, and the height of him is 170 cm.

A. Electrode configuration

This article consider the previous work of electrode configuration [3] and made three electrode configuration on the upper arm as shown in Fig. 1. This study made three electrode configuration using the electrodes 1 and 5, 2 and 3, 1 and 4. Electrode 1 and 5 were placed on the lateral and medial plane, electrode 2 and 3 were placed on frontal plane, and electrodes 1 and 4 were placed on medial and lateral plane. Electrode 6 act as reference electrode and it was placed on frontal plane of forearm where near the inside of palm.

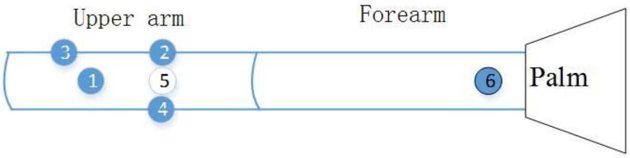

Fig. 1. Schematic diagram of electrode positions which consists of three pairs for elbow movements.

B. Measurement system design

Fig. 2 shows the block diagram of the device for bio-impedance measurement. A modified Wien oscillator generates 20-kHz, 50-kHz and 70-kHz sine signal to the Howland constant current source. A one-channel bio-impedance measurement system was applied in this study, two electrodes inject different frequencies constant current from Howland constant current source to upper arm and extract the voltage which is correspond to the bio-impedance of body segment. The voltage signal which correspond to bio-impedance was extracted after high-pass filter, Instrument amplifier INA 128, rectifier, low-pass filter, coupling circuit and amplifier circuit using. Labview2012 with NI-DAQ was applied in this case.

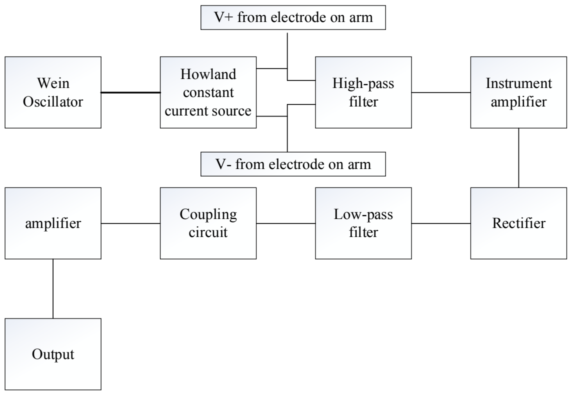

Fig. 2 The diagram of one channel of bio-impedance measurement system.

IV. Result

The result show there has high correlation between bio-impedance changing and elbow joint angle movement in 50-kHz and 70-kHz condition. However, the result of 20-kHz is not stable in the bio-impedance measurement. 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 resistor are stable. But in the case of human arm the result of frequency 20 kHz is not stable because of the limitation of body composition. This article only test the elbow flexion evaluation using 20-kHz due to the unstable result. The average of correlation between bio-impedance changing and elbow flexion movement at 20-kHz is 0.687. Fig. 3 shows the result of 20-kHz experiment. Thus, 20-kHz is not fit in this case of study. The average of correlation between bio-impedance changing and elbow flexion movement for each frequency and each electrode configuration in 50-kHz and 70-kHz condition as shown: 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. 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. Thus, electrode configuration 1 with 50-kHz contribute the optimum result for the elbow flexion movement which is 0.998. Electrode configuration 1 with 70-kHz got the optimum result for the elbow extension movement which is -0.999. The result of three electrode configuration shows the electrode configuration don't significant due to each configuration got high correlation result and bio-impedance is useful to evaluate using joint angle of elbow movement in 50-kHz and 70-kHz condition in this case. The Fig. 4, 5, 6 and 7 shows the one of result from bio-impedance measurement with the elbow flexion and extension measurement in 50-kHz and 70-kHz condition.

The correlation measurement in this article is calculate by Pearson correlation equation as equation (6):

$$\rho(X,Y)=\frac{Cov(X,Y)}{\sigma X\sigma Y} \tag{6}$$

Where:

Cov is the covariance.

σ is the standard deviation.

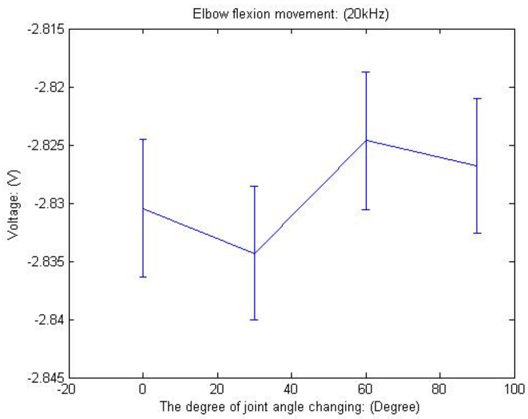

Fig. 3 The result of bio-impedance changing with elbow flexion movement from 0 degree to 90 degree in 20-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

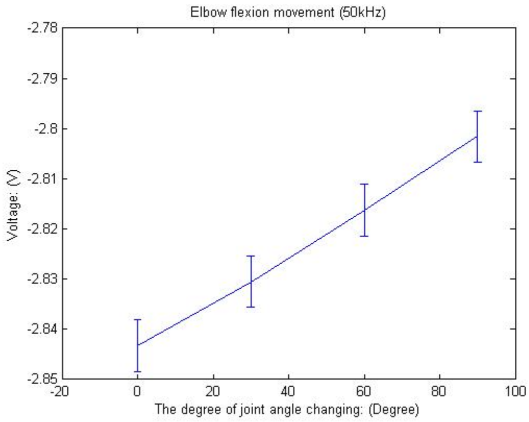

Fig. 4 The result of bio-impedance changing with elbow flexion movement from 0 degree to 90 degree in 50-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

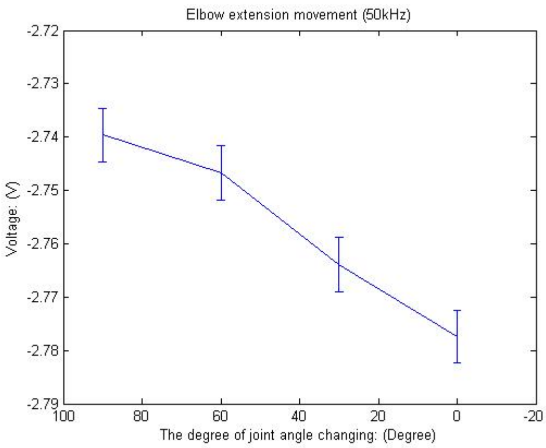

Fig. 5 The result of bio-impedance changing with elbow extension movement from 0 degree to 90 degree in 50-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

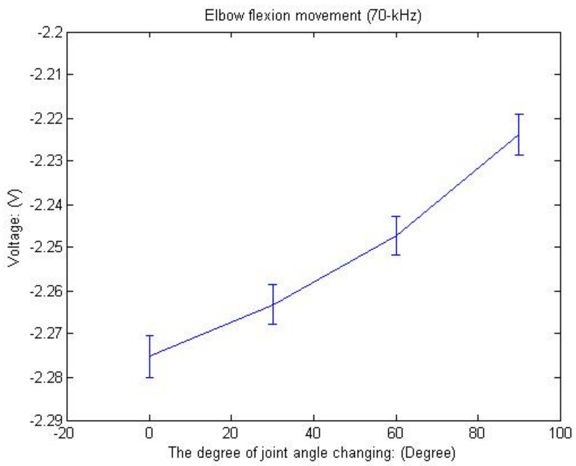

Fig. 6 The result of bio-impedance changing with elbow flexion movement from 0 degree to 90 degree in 70-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

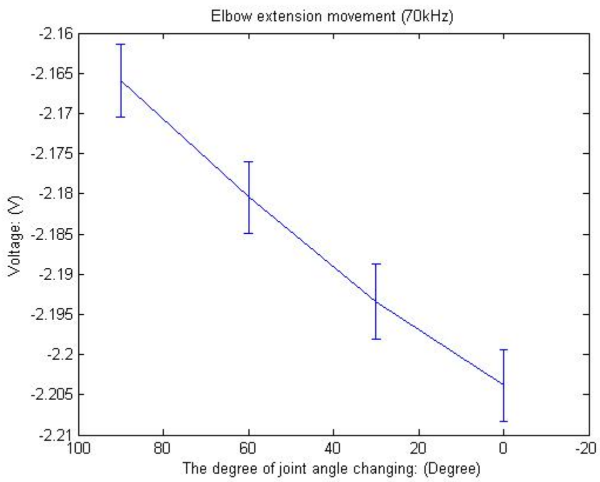

Fig. 7 The result of bio-impedance changing with elbow extension movement from 0 degree to 90 degree in 70-kHz condition. X axis is the joint angle changing (degree), Y axis is the voltage changing (V) correspond to bio-impedance changing.

V. Conclusion And Discussion

The correlation between bio-impedance changing and elbow joint changing was calculated by a one-channel and multi-frequency bio-impedance measurement system. The literature review has shown different frequency cause different result of bio-impedance measurement [5, 6]. Low frequency of injected current cause the cell membrane act as an insulator, high frequency cause the cell membrane act as a perfect capacitance [6]. This article compare the correlation from three frequencies of bio-impedance measurement and elbow joint movement. According to the experiment result, the result from 20-kHz condition was not stable in this case. The result of 50-kHz condition and 70-kHz condition show high correlation between bio-impedance changing and elbow joint angle changing in each electrode configuration. Thus, 50-kHz and 70-kHz conditions are suitable for this case. There has some limitation in this study. The first limitation is the data which come from only one subject. The second limitation there has no concern of the body parameter, such as body mass index (BMI). This study will find the result of multi-subject in future and each subject has different BMI to solve these two limitations.

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