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Accuracy enhancement in low frequency gain and phase detector (AD8302) based bioimpedance spectroscopy system

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ABSTRACT

Bioimpedance spectroscopy (BIS) is the measurement of the impedance of biological tissues. In the development of a low cost, portable BIS system the gain and phase difference detection (GPD) method is usually used. However this method suffers from low accuracy at low frequencies due to the presence of spikes or peaks. Detection and removal of these peaks will improve the performance of the GPD based BIS system at low frequencies. Peak detection in physiological signals is a well developed area. A lot of algorithms have been developed in the past for the determination of peaks in signals and their time of occurrence. For real-time processing, microcontroller based peak detection algorithms have also been developed in the past. In this paper, the problem of the GPD method at low frequency is examined closely and then three algorithms were used to mitigate it. The first is based on a moving average filter, the second is a simple peak detection and elimination (SPD) and the last is a peak detection based on the frequency of the input signal to the GPD (SFPD). These algorithms were evaluated with both simulated and measured data. Four parameters were used to indicate the performance of the algorithms; run-time, RMSE, sensitivity and positive predictability. The RMSEs were less than 0.17 for moving average, 0.07 for SPD and 0.08 for SFPD. The run-times was less than 10 ms for SFPD while that for the SPD and moving average were around 30 ms and 80 ms respectively. In all it was found that the algorithms based on peak detection have better results. The computational simplicity of the algorithms makes them suitable for microcontroller based implementation.

1. Introduction

In bioimpedance spectroscopy (BIS) the bioimpedance spectra of tissues are measured within a frequency range typically between 10 Hz and 10 MHz. This is generally done by injecting a weak sinusoidal current into the tissue and measuring the induced voltage magnitude and phase at each of the frequencies. The impedance magnitude and the phase of the tissue can then be estimated through data processing [1]. BIS has extensive use in the medical field for body fluid composition [2]. In their design of a portable version of BIS, Yang et al. proposed a method based on the magnitude-ratio and phase-difference detection [3]. The method made use of a gain and phase detector (GPD) chip to measure impedance. Though this greatly decreases the complexity of a BIS system, it cannot measure impedance values at frequencies below 20 kHz with an acceptable accuracy due to the limitation of the GPD itself. Bonnet et al. recently developed a potable BIS system with a frequency range of 2–500 kHz [4]. They used Cole-Cole model to fit the measured data and estimate hydration level in dialysis patients. The GPD based BIS's performance degrades at low frequencies. Typically the lowest corner frequency can be brought down to about 20 kHz through hardware modifications [3]. However low frequency bioimpedance holds valuable information [5]. This limitation is due to artefacts introduces in the signal in the form of spikes or peaks. There are several peak detection algorithms developed in the pass in the areas of mass spectroscopy [6], chromatography [7], Geophysics [8] astrophysics [9] sound signal processing [10], image processing [11], power electronics [12] and of cause in physiological signal processing for PQRST extraction [13] and for diseases cause detection through nano-bio sensors [14]. Peak detection in multi-modal physiological signals have also received attention these recent years [15]. In all these algorithms the main goal is to determine a given point (peak) and its point in time (or space). To do this the algorithm needs parameters like threshold value and window length. Automatic techniques to determine these parameters have been proposed for physiological signal [16].

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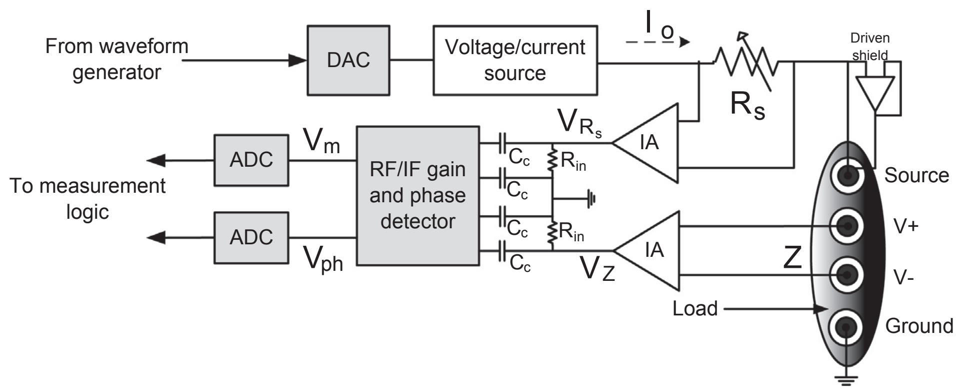

Fig. 1. Bioimpedance spectroscopy system based on Gain and phase detector.

Microcontroller based peak detection algorithms have also been developed for stand-alone, real-time processing and monitoring of physiological parameters [13]. Even though these algorithm are efficient in detecting peak point they are not suitable for our problem as we aim to detect a series of points and eliminate them. This paper closely examines the problem that this method has at low frequencies and proposes three algorithms to detect and remove the corrupted measurements from the measured data. The algorithms were optimized in speed and accuracy and can be easily implemented in a micro-controller chip. The outline of rest of this paper is as follows: first the structure of the GPD based BIS system is presented and the problem of the GPD at low frequency is described. Then the proposed algorithms for peak detection and elimination is discussed. After that the results using simulated and measured data are presented and discussed. A conclusion was drawn at the end.

2. Materials and methods

2.1. System structure

The structure of the GPD based BIS system is given in Fig. 1. The system consists mainly of a waveform generator and an RF/IF gain and phase decoder (GPD) (AD8302, Analog Devices, USA) IC. A sinusoidal signal of variable frequency is applied to a series of current sensing resistor, R_S, and a load. Differential voltage drop across the R_S and load are measured and sent to the GPD through two instrumentation amplifiers. The operation of the GPD is as follows; it takes two signals as input and produces two DC output signals which are proportional to the ratio of the magnitudes ratio and the difference in the phase of the two inputs. The output voltages range from 0 V to 1.8 V. The integrated circuit (IC) is optimized for RF/IF frequencies up to 2.7 GHz [17]. However, the IC can also be adapted for use at lower frequencies with modifications of the input circuit. The input coupling capacitors, C_c, which determines the high-pass corner frequency can be increased so as to improved performance of the GPD at low frequencies [18]. Using C_c of 1 µF will lower the corner frequency down to about 20 kHz. The GPD comprises a closely matched pair of logarithmic amplifiers and also includes a phase detector of the multiplier type at the outputs of the two logarithmic amplifiers. The outputs of the GPD (V_m and V_{ph}) can be expressed as [17]:

$$V_m = K_G \log\left(\frac{v_z}{v_{R_s}}\right) + 900\text{ mV} \tag{1}$$

And

$$V_{ph} = K_P((\theta_z - \theta_{R_s}) - 90^\circ) + 900\text{ mV} \tag{2}$$

where K_G and K_P are constants given as 600 mV/decade and −10 mV/degree respectively [17]. Assuming that the same amount of current is flowing through R_s and Z the magnitude of the load impedance can be obtained thus:

$$Z = R_s\left(10^{\left(\frac{V_m - 900\text{ mV}}{G_k}\right)}\right) \tag{3}$$

Similarly the phase of the load impedance can be obtained by:

$$\theta_z = \theta_{R_s} + \left(\frac{V_{ph} - 900\text{ mV}}{P_k} + 90^\circ\right) \tag{4}$$

After closely examining the output signal from the GPD at low frequency in put signals, it was noticed that there are spikes or peaks occurring in the signal. Furthermore it was noticed that these spikes occurred with a frequency two times that of the input signal ($2f_{in}$) as shown in Fig. 2 where the input signal is superposed with the output. These spikes are due to the very nature of the GDP which is essentially a logarithmic amplifier. In Eq. (1), when v_{R_s} is approaches zero volts V_m turns to infinity causing the spike. Since in one period the sinusoidal signal through R_s approaches zero two times, the spike occurs at a frequency that is double the input signal frequency. It was also observed that the duration of the spikes depends on the frequency of the input signal. To enhance the performance of the GPD at low frequencies these spikes or peaks need to be detected and removed. Three algorithms were used for this purpose. The first was a normal moving average filter while the other two are algorithms of peak detection and elimination. The correlation between the input signal frequency and output of the GPD was utilized to improve the speed and accuracy of the algorithms.

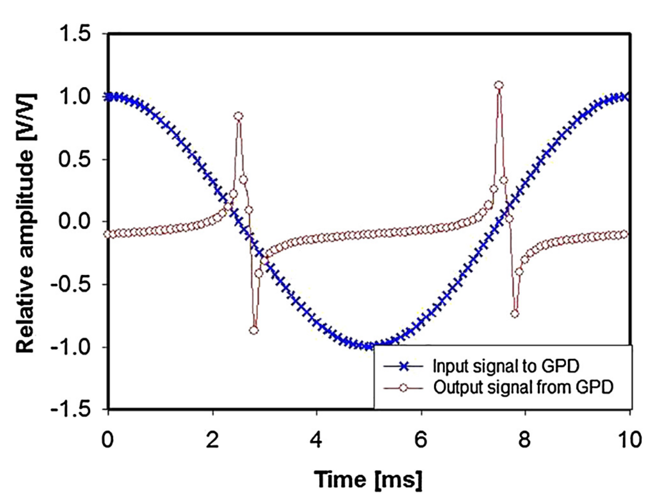

Fig. 2. Depiction of the problem with GPD at low frequencies (Signal frequency 100 Hz).