DEVELOPMENT OF NON-CONTACT CAPACITIVE COUPLED ELECTRODES FOR BIO-POTENTIAL SIGNAL ACQUISITION

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Abstract- Patient monitoring is one of the challenging and significant tasks in healthcare sector. Generally bio-potential electrodes are used to extract low amplitude physiological signals from the human body and for continuous healthcare monitoring of patients in hospital. The conventional wet electrodes provide an optimal signal, but it needs skin preparation and the application of electrolytic gel before attaching electrodes to the skin surface. The gel becomes dry after some time and is uncomfortable for wearable applications. The limitations faced in wet electrodes can be set aside by a new class of electrodes which can be coupled to the skin without any contact using capacitive coupling effect. The proposed type of electrodes can be easily mounted on to a patient clothing to create a nonintrusive wearable bio-potential recording apparatus. An impedance matching circuit with bootstrap technique is used for developing non-contact electrodes based data acquisition system. Hence the aim of the project is to design a non-contact capacitive coupled electrode with suitable amplifying circuit and signal conditioning for wearable or ambulatory based bio-potential acquisition system.

Keywords- Bootstrap, Bio-potential electrodes, Impedance matching non-contact capacitive coupled electrodes.

I. INTRODUCTION

The electrical activity of the body is due to the movement of ions across the cells and tissues. The potential developed due to the movement of these ions is known as bio-potential. Electrocardiogram (ECG), Electromyogram (EMG) and Electroencephalogram (EEG) are some bio-potential signals which play an important role in patient health monitoring, diagnosis, and treatment. This bio-potential signal in the form of ionic current in our body is converted into electric current by using bio-potential electrodes that can generally be categorized as intrusive or non-intrusive. The main disadvantage of intrusive electrode is it needs surgery for electrode implantation or it needs contact with the interstitial body fluids and is risky because they will cause infections or allergies. In general one of the non-intrusive kinds is wet electrode which consists of a base metal usually Ag (Silver) with its ionic compound Ag–AgCl (Silver–Silver Chloride) deposited on to its top and the charge transfer from the body to the electrode is accomplished using the electrolyte gel that reduces the contact mismatch between the signal source and the electrode by reducing the skin impedance. In the metal electrolyte interface charge transfer occurs through chemical oxidation reduction reactions. Thus in wet electrode type body and the electrode were connected via resistive coupling. Such electrodes are the standard electrodes used in clinical and research applications.

The researchers have been made several attempts to overcome the limitations of wet electrodes. Advances in technology include one class of surface electrodes that does not use electrolytes. These electrodes are referred to as dry electrodes and non-contact capacitive electrodes which rely on a metallic surface in direct contact to the test subject. In dry electrode conductive coupling occurs directly between skin and electrode since electrolyte is not used anywhere. In non-contact electrode type the signal on the skin capacitively couples to the sensing plate through dielectric material to achieve the capacitive effect which was first reported in 1968 by Richardson. Ruffini et al. in his paper explained about sensor arrays made of multi-walled carbon nanotubes for EEG acquisition by penetrating the stratum corneum of the skin to reduce noise. The limitation is it may cause some allergies in the patient since it is penetrating the skin. In 2004 Jaime et al. developed a device for detection of ECG inter-beat intervals and respiratory signals through clothing using CCNE (Capacitive Coupled Non-contact Electrode) method and further work is require for checking fidelity of ECG signals to find out whether clinical diagnosis is possible. In 2006 and 2007 Lim et al. developed capacitive electrodes ECG measurement system on a chair or for measuring ECG signals during sleep by attaching electrodes on to the bed without any conductive contact utilizing a high input impedance active electrodes but however the signal quality is less in both the cases. In 2008 Gaetano et al. proposed a wearable device for measuring EEG signals using dry contact electrodes with ultra high input impedance front end but the signal is prone to be noisy still. In 2012, Chi et al. combined the input capacitance cancellation circuit and the bootstrap circuit with the active electrode but the limitation is the capacitance feedback in the system may vary continuously with time.

In this paper we proposed a simple method of active electrode with buffer followed by bootstrapping where it reduces many complexities. Therefore recording of bio-potential signals for long term physiological
monitoring will be simple and convenient. This paper presents the acquisition of ECG signals by non-contact capacitive coupled electrodes for various dielectric thicknesses. The acquired bio potential signals by this type of electrodes are compared with wet as well as dry electrodes.

II. MATERIALS AND METHODS

A. Non-contact capacitive coupled electrodes
The conductive electrode surface forms a coupling capacitance between the subject’s body and the electrode as shown in Fig. 1. The coupling capacitance depends mainly on the thickness and the dielectric constant, of the dielectric material located between the electrode and the subject’s skin. Using a capacitor model formula shown below in equation (1), the amount of measurable capacitance is estimated, where \( \varepsilon_r \) is the relative static permittivity of dielectric, \( \varepsilon_0 \) is the permittivity of free space, A is the surface area of the plates and \( d \) is the thickness of dielectric [1].

\[
C = \frac{\varepsilon_r \varepsilon_0 A}{d}
\]  
(1)

The capacitive electrode was designed so that its input impedance would be significantly larger than that of the skin electrode impedance to minimize interference caused by motion artifact and unwanted common-mode voltages. The electrical behaviour of wet and dry electrodes can be compared with capacitive electrodes by their equivalent circuit model given in Fig. 2 where it is divided into two parts; the skin electrode interface and the electrode-electrolyte interface. In Fig. 2 the capacitor \( C_1 \) is due to the capacitive coupling effect formed between body tissue and electrode. Since the outermost layer of the skin known as epidermis behaves like a RC circuit the resistance \( R_1 \) is included. The resistance \( R_{body} \) represents the dermis and subcutaneous layer of the skin. The half cell potential \( V_{hc} \) is due to the charge distribution between skin and the electrode. In the electrode electrolyte interface the capacitor \( C_d \) represents the double layer and the resistance \( R_d \) represents the leakage resistance associated with the double layer in case of wet electrodes. The \( R_e \) and \( C_e \) represents the resistance and capacitance for the dielectric material in non-contact capacitive coupling electrodes.

B. Active electronics
Impedance mismatching is the main problem with capacitive coupled electrode system. Since ECG signal source i.e. our body is of high impedance in order to achieve maximum power transfer from the source to electrode there is a need to match the impedance between them. This impedance transformation is done by an electrode called active electrode attached to the back of the sensing part. Fig. 3 is a schematic of active electronics consists of a buffering circuit followed by an op-amp bootstrapped through resistors \( R_1 \) and \( R_2 \). The capacitor \( C_1 \) is used in series with the input in order to block the dc signal.

For an ac coupled voltage follower it is necessary to provide a ground path for bias current so it can be done through a biasing resistor. However this biasing resistor will reduce the input resistance of the voltage follower circuit drastically. Therefore in order to get higher input impedance the bias resistors \( R_1 \) and \( R_2 \) are bootstrapped. The drop across the resistor \( R_1 \) is \( (V_1 - V_2) \), which is almost zero. Therefore current
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through R1 is almost zero and as a result ultra-high effective input impedance is achieved to acquire low level ECG signals from high source impedance without any signal distortion.

III. DATA ACQUISITION FOR ECG

The data acquisition block diagram is depicted in Fig.4. The ultra-high impedance front end is followed by a low power, high performance; single supply instrumentation amplifier AD623 from Analog Devices configured for the gain of 10 for ECG. Output signal from the finite gain op-amp circuit (instrumentation amplifier) is input to a filter and amplifier unit. Filter and amplifier unit consists of 4th order Butterworth high pass filter with a lower cut off frequency of 0.5 Hz since ECG signal falls in the frequency range of 0.5 Hz to 100 Hz. This filter serves to remove the DC offsets as well as other low frequency signal noise (mostly baseline wander). Followed by this high pass filter a 6th order Butterworth low pass filter is used to reduce the sensitivity to out of band noise by restricting the upper cut-off frequency to 100 Hz. Twin-T notch filter is used to reduce the effect of 50 Hz power line interference noise in ECG acquisition circuit. Finally, an amplification stage is introduced in the end of the signal conditioning pipeline. This post amplification stage further increases the signal to noise ratio of the signal and boosts the signal voltage to a range appropriate for sampling. The second stage amplification and filters are implemented using high precision operational amplifier OPA2344 from Texas Instruments designed for low-power, battery equipped medical devices. The overall gain of the system is set to 1000.

C. DRIVEN RIGHT LEG CIRCUIT

The common mode noise is the big problem in capacitive ECG measurement system due to high impedance between the capacitive electrode and the body. For the suppressing the common mode noise the acquisition system requires a common mode noise cancellation circuit. Instead of grounding the patient the reference electrode is connected to a Driven-Right-Leg circuit. As a result the common-mode voltage on the body is sensed by the capacitive electrode by a sensing plate; the signal is inverted, amplified and fed back to the right leg for cancelling the common mode noise.

IV. EXPERIMENTAL SETUP

Three different types of electrodes were used for the experiment purpose. Pre-gelled silver/silver chloride electrodes as wet electrodes, conductive disc made of stainless steel with (disc diameter 1 cm) were employed as dry contact electrodes and capacitive electrodes. In this study, capacitive electrode operates through cotton cloth of various thicknesses in mm. The experiment was conducted on the male subject using three capacitive coupled non-contact electrodes. Velcro straps were used to hold the electrodes on to the body over a cotton cloth shown in Fig.5 and the ECG signal was recorded using a CRO. All the test subjects were provided with the same type of cotton cloth during the test. For reducing the triboelectric effect of static charges 100% cotton cloth was used.

V. NOISES IN CAPACITIVE ELECTRODE MEASUREMENT SYSTEM

The noises encountered during ECG signal acquisition is 50Hz power line interference, displacements in the electrode-to-skin distance due to extra cardiac muscle...
movements, EMG from the chest wall, electrode contact noise electrosurgical noise, baseline wandering, instrumentation noise, and motion artifacts. Hence, post signal processing is required to minimize the effect of artifacts and thereby improve the signal quality.

D. Signal processing
As the data obtained from the capacitive coupled non-contact electrodes is prone to be much noisy, it is necessary to post-process the data. Different signal processing techniques such as Gaussian filtering, Median filtering, moving window type and moving average filters were used in MATLAB signal processing tool box to remove noise from the obtained data but moving average filter is easier to implement for the noise removal technique since it will reduce random noise and at the same time it will retain the sharp step response.

The moving average is faster than any other digital filters because for every two computation it uses single point regardless of the filter length. It needs only addition and subtraction operations rather than complex operations in other digital filters and also indexing is very simple. The entire algorithm uses integers for calculation instead of float point so the filter is very fast.

E. Moving Average filter Implementation
The filter is implemented by averaging each and every point in the input signal to produce each point in the output signal. The mathematical equation for the filter is given by (3) below

\[ y[i] = \frac{1}{M} \sum_{j=0}^{M-1} x[i+j] \]  

(1)

In the above equation, \( x[ ] \) represents the input signal, \( y[ ] \) is represents the output signal, and \( M \) is the number of points used in the moving average. The equation (3) only uses points on one side of the input signal for the calculation of the output signal. There is an alternative method which uses symmetrical points around input signals to produce the output signal. It is easy to program the moving average using one sided method rather than symmetrical method but the one sided method produces a relative shift between input and output signal.

VI. RESULTS
A. ECG ACQUISITION RESULTS
The designed non-contact capacitive electrodes were mounted on to the chest belt and ECG waveforms are recorded from the test subject using CRO (Tektronix MSO 4104 model). The CRO snap shot of ECG obtained with the conventional Ag/AgCl electrodes, stainless steel dry contact electrodes, and capacitive coupled electrodes are shown in Fig.6, Fig.7 and Fig.8 respectively.
DISCUSSION

In this study, non-contact capacitive-coupled electrodes were evaluated by comparing with wet electrode and also dry-contact electrode results. The test results analysis shows that the ECG signal obtained with the proposed method is very much closer to the ECG signals obtained with the standard method on visual perception. This study has shown ECG signal acquisition can be obtained through new noncontact capacitive coupled electrodes. More work is required to study the reliability of these electrodes for long term wearable health monitoring.

REFERENCES