A Review of Capacitive EEG Sensor

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Abstract— Brain activity is an essential key to understanding the psycho physiological states of humans. Conventional wet electrodes are commonly used to measure EEG signals; they provide excellent EEG signals subject to proper skin preparation and conductive gel application. However, a series of skin preparation procedures for applying the wet electrodes is always required and usually creates trouble for users. Using non-invasive electroencephalograms (EEG) with capacitive electrodes, brain states can be measured and analyzed without complex medical procedures. This paper reviewed about capacitive electrodes which used for neural monitoring.

Key words: brain Signal, Electroencephalography (EEG), Capacitive Electrodes

I. INTRODUCTION

Electroencephalography (EEG) is one of the most widely used methods for evaluating the electrical activities of the brain. Due to the advantages of non-invasive measurement and the capability of long term monitoring of the EEG signal, an electroencephalograph plays an important role in brain examinations and studies. EEG is a standard procedure used in clinical and research applications, especially, in the diagnosis of the brain diseases such as epilepsy, sleeping disorder and abnormal behaviour [1]. For the measurement of bio-signals such as electrocardiogram (ECG), electromyography (EMG), and neural signals including electroencephalogram (EEG), Ag/AgCl electrodes and other metal based electrodes that utilizes electrolyte gel for the enhancement of contact between the skin and electrode have been broadly used. Although this conducting gel has an advantage of inducing good and robust contact, it also has several problems such as drying-out of the gel over time, skin irritation, and electrical short between neighboring electrodes when the distance between the electrodes is small. In addition, many patients display discomforts when using the medical devices that utilize electrolyte gel. In contrast, dry electrodes based on metallic materials prevent such problems of gel-based electrode, and thus diverse types of dry electrodes have been Developed [1].

Although these dry electrodes have since been broadly used, they often cause the following problems: poor contact impedance compared to gel electrodes, an inconsistency in contact area due to its rigidness while the subject is in motion, and a possibility of causing damage to the skin over the long period of time. Therefore, the dry electrodes is disadvantageous when used on subjects with motion as well as causing discomforts for the patients due to stiffness of the metallic material [2]. To address these problems, polymeric dry electrodes have been developed. They enhance the contact impedance with the skin and prevent skin irritations or allergic reactions after a long term use [3]. Also, the metal layer, which is directly contacting to the skin, are damaged easily, and long-term reliable wearing is still problematic. To overcome all these limits, the noncontact electrodes (or capacitive electrode) avoiding direct ohmic contact with the skin by capacitive coupling has been developed. These electrodes are advantageous in recording EEG signals through hair. This capacitive monitoring method is suggested one of the most useful tools to live a health life. In the future, this method is expected to apply to various parts around our life with developed technology.

II. DIFFERENT TYPES OF ELECTRODES

	Advantages	Disadvantages
Wet type	Reduced motion artifacts	Electrolyte required, Gel smearing
Dry type	No electrolyte require, easy application	Movement artifacts
Capacitive type	No skin preparation, Reusable, no electrolyte require	High input impedance

Table 1: Different Types of Electrodes

The main characteristics of each type of electrode are summarized in table. Here it is justified why the capacitive electrodes were chosen.

III. HISTORY, PRINCIPLES & FEATURES OF CAPACITIVE ELECTRODES

Capacitive electrodes operate with the displacement currents instead of the real charge currents, and its electrolytic electrode–skin interface is replaced by a dielectric material, an electrically insulated layer or air. Capacitive electrode measures the bio-potential through the insulating materials by forming capacitive interface between the skin and the electrode face.

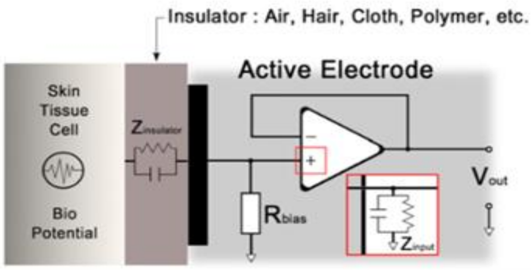

Fig. 1: capacitive electrode circuit [5]

A capacitive method of picking up bio potentials was proposed in 1967 by Richardson [4] where the active electrode concept was taken into account. The results demonstrated that capacitive electrodes can be used to pick-up ECG signals with good signal characteristics in comparison to wet electrodes. The new procedure based on capacitive measurements of skull potentials, while no direct electrical contact with the scalp is made and therefore no gel is needed, was first reported by Matsuo et al in 1973 using barium titanate as the insulating material [5].

Researchers at Quantum Applied Science and Research (QUASAR) developed a sensor that is able to measure the ECG of a fully clothed person standing within a range of about 25 cm. In 2005, QUASAR developed a compact version of the sensor and named it the capacitive coupled noncontact electrode (CCNE), Sullivan et al. (2007) from Institute for Neural Computation, University of California San Diego, designed an integrated sensor which combines amplifications, band-pass filtering, and analog-to-digital conversion within a 1 inch diameter enclosure [6]. This non-contact bio-potential sensor couples capacitively to the human scalp through hair for EEG. In 2008 at the "Institut für Elektrische Messtechnik und Grundlagen der Elektrotechnik" of the TU Braunschweig, Oehler et al. designed a capacitive electrode for EEG measurements through hair [7]

Recently Chi et al. designed an innovative micro power non-contact EEG electrode with active common-mode noise suppression and input capacitance cancellation [8]

The capacitive electrode designed such 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 signal on the skin capacitive couples to the sensing plate coated with dielectric material to achieve the capacitive effect. The coupling capacitance depends mainly on the thickness and the dielectric constant of the material located between the electrode and the subject's skin.

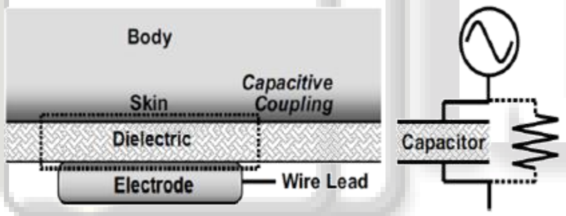

Fig. 2: Principle of Capacitive EEG electrode [8]

IV. Classification of Capacitive Signal Recording According to the Method

The recording methods of bio signals using the capacitive electrodes can be categorized as 'Built-in', 'Helmet', 'Band and Film'and 'Pad & Chip' type.

A. Built-in electrode:

During the patients' daily life, these electrode can collect bio signals, especially, ECG, which is one of the most important indicators in diagnosis of cardiovascular disease. Especially, through continuous monitoring of ECGs, mortality by an acute cardiac arrest will be greatly decreased. The representative example is the capacitive electrodes built-in chiar used in offices [9,10]. Signals can be measured from the electrodes attached to the back of the chair. Just by sitting on the chair without having to remove clothes, the signals from the patient are collected [17]. The electrodes are generally made from metal-coated plates. The noise level largely depends on clothing properties, as different noise levels are detected from subjects wearing different clothes.

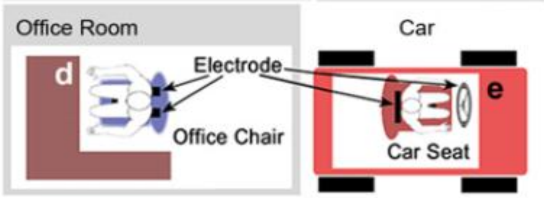

Fig. 3: built in electrodes placement [18]

B. Helmet Electrode:

When people acquire EEG signals by the conventional method, the inconvenience lies in using the conductive gel, setting up the numerous electrodes, and undesirable appearance due to complicated lines. In order to resolve these problems, some researchers developed an EEG helmet, and this provides a direct access of EEG signals even through scalp hair. M. Oehler et al. [11] presented a 28-channel EEG helmet system using the capacitive electrodes and measured steady-state visual evoked potentials (SSVEPs) even through scalp hair. Using this system, detection time decreased by 3 times than when using the galvanic EEG SSVEP, and this is short enough to establish a proper communication for human machine interface (HMI). C. Wehrmann et al. [12,15] developed a helmet system with capacitive electrodes and wireless connection that enables movements during EEG recording.

Fig. 4: helmet electrodes placement

C. Band & Film Electrode:

Although a built-in and helmet system enables the inconspicuous measurement of bio signals without directly contacting the skin, it is still a great challenge to use these technologies for mobile or wearable system, one of the hottest topics in Healthcare, military and BCI. For example, monitoring the patients over extensive periods of time will make the patients feel that the doctor is always with them, and thus safe. For this purpose, diverse band and film electrodes have been developed. These capacitive electrodes can be fixed by caps, belts, or tapes to the skin, and are flexible. These properties facilitate electrodes to keep close contact with the skin and to allow patients to move freely with decreased motion artifacts. J-W. Jeong et al. [13, 16] made the electrode with thickness of < 1 μm that can measure various electrophysiological signals (EP) such as ECG, EEG and EMG using the MEMS technology. Some electrodes are made from flexible fabric for wearable applications. Capacitive electrode embedded in clothes made it possible to acquire bio-signals for a whole day [14, 18].

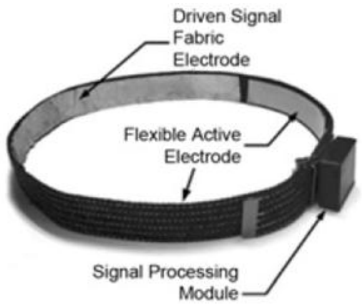

Fig 4: band & film electrodes placement

V. CONCLUSION

We reviewed various capacitive electrodes focusing on the type of measuring method. Capacitive electrode has been developed for various applications due to its advantages such as non-contact, safety, no leakage in currents or electrical shorts, and etc. By adopting the capacitive electrode, gel free, mobile, and inconspicuous long-term monitoring of health has been realized. This technology features several practical advantages like omitting the need of direct conductive contact to the naked skin and hence allowing measure to the clothes.

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