Comparison of dry electrodes for mobile EEG system

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Abstract: The main objective of this study was to evaluate two types of dry EEG electrode. In the paper, we describe the comparison of two comb electrodes. The first was an electrode based Ag-AgCl alloy and the second was electrode based on a flexible conductive polymer. Testing of these electrodes was performed based on the need to increase convenience when measuring EEG signals while maintaining the same signal characteristics.

1 Introduction

Most brain-computer interfaces (BCI) are based on brain wave recording using electroencephalography (EEG). EEG technology is a non-invasive method for recording signals derived from brain activity. EEG uses electrodes deposited on the human scalp to capture the signal that passes through the skull. This signal is considerably weakened compared to the original, so the EEG device must be suitably designed to capture it [1].

In general, there are several types of EEG electrodes. Disc electrodes used in medicine require the use of conductive electrode for optimal impedance and data quality. However, the use of a gel has serious disadvantages and problems which are particularly noticeable when capturing EEG signals in real-life conditions by using EEG device by laymen. Therefore, so-called dry electrodes that do not require the presence of any additive are used for BCI applications. The use of dry electrodes that do not require gel is often very advantageous as it provides a quick setting of the device without time-consuming preparation, but often brings new problems such as comfort and signal quality. Recent studies focus on the use of EEG signals in mobile BCI applications. Such applications should be based on the use of such EEG devices that should be as comfortable as possible and should be easy to use for the individual.

Dry electrodes have the ability to make EEG technology available for mobile applications. Mobile EEG applications and EEG devices can make life easier or more comfortable for many people. There are several areas of use of Brain to computer interfaces (BCI) such as games or assisting people. BCI-based assistance may include applications to improve the nervous system or restore nerve bonds in the case of paralysis [2].

The EEG device, which would allow ordinary people to use the BCI interface in everyday life, has several conditions. These conditions are suitable device design, ease of use in non-clinical settings, comfort, painlessness, and cleanliness. Medical EEGs use conductive gel electrodes and are made in the form of an elastic cap. The mobile EEG should be usable without the need for shaving the head and comfortably enough, so dry EEG electrodes should be used. For these reasons, we have performed the experiment of the using and properties of dry electrodes.

2 Materials and methods

In the experiment, two types of electrodes were compared. As the first step, the resistance of the electrodes was evaluated using the Volt-Ampere method. In the second part, the quality of the signals measured with these electrodes was compared.

2.1 EEG headset

The OpenBCI headset was used to measure the EEG signal. The headset is designed as a plastic 3D printed construction, that allows place electrodes up to 35 different positions by standard 10/20 configuration system. In the experiment, the brain signal from 10 locations of frontal and temporal lobes was measured.

The headset works wirelessly. The measured data is sent via the Bluetooth 4.0 wireless communication protocol to the USB dongle receiver. The headset can also store data directly on a microSD card when the device is not connected to any wireless receiver. The entire system is powered by batteries, providing greater patient electrical safety and portability [3].

The input impedance of the amplifiers in the headset is $500M\Omega$. The lead resistance of the electrode is negligible compared to the large impedance at the amplifier input [4].

2.2 Post dry electrode

The first dry EEG electrode TDE-200 was used. The electrode is also known as Post electrode, shown in Figure 1.

Figure 1: TDE-200 dry EEG-electrode (Post electrode)

Figure 2: Datwayer Brush electrode

It is a dry electrode, made of Silver-silver chloride (Ag-AgCl) alloy with a diameter of 10 mm. This electrode is specific in that it contains 12 pins to improve contact through fur or hair. The pins are 2 mm long to provide good contact with the skin surface through the hair. They provide accurate and clear transmission of surface biopotentials. The electrodes connection is provided by a screw to which the conductive cable is then attached [5].

The advantage of the electrodes is the low resistance due to the metal composition. The use of electrodes does not require the addition of a moisturizing gel to improve conductivity or to remove hair from the measured head area. Thanks to the small pins, the electrode can reach the skin surface.

The disadvantage is the painful setting of the electrodes before the measurement and the occasional subjective pain even during longer measurements. Pins often push too much on the skin, but leave no injuries.

2.3 Brush electrodes

The second tested sample was dry Brush electrode by Datwyler, shown in Figure 2. The electrode is designed for better comfort. The electrodes are based on a flexible conductive, elastic main body with a conductive coating covering the contact area, ensuring comfort during monitoring and setting of the headset. Brush electrode also has small pins, but these are soft and movable due to that they are made of conductive polymer. There are 15 pins with a length of 5 mm and the contact area has a diameter of 12 mm. They are attached to standard snap lead cabling.

The advantage of the Brush electrodes is that they are designed for dry signal acquisition, so they do not need moisturizing gels or hair removal for using. Thanks to longer pins they can work through the hair. Elastic material ensures an easier setting and painless measurement on the skin [6].

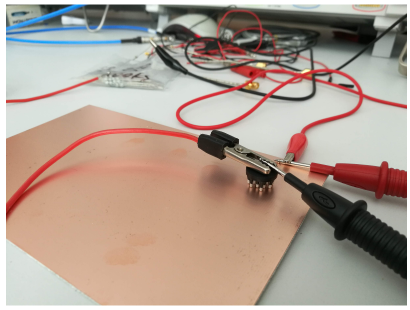

Figure 3: Electrode measurement

3 Electrode electrical properties measurement

Due to the low resistance and voltage values of the electrodes, the Volt-Ampere method to measure the resistance was used to ensure the most accurate result. The measurement using a copper plate was performed, as it is shown in Figure 3.

The amount of voltage and the current passing through the electrodes was measured. Because of the small size and irregular shape of the electrode electrodes, we used the copper plate on which we placed the electrode to measure. Then we measured the current passing through the plate and the end of the electrode and the voltage between these points.

3.1 Electrical features of the Brush electrode

As the first was measure the Post electrode. The Post electrode is made of Silver-silver chloride (Ag-AgCl), therefore, lower resistance was assumed. This assumption was confirmed by measurement.

The measurements showed electrode voltage values of 2.6 to 4.3mV and current values were measured in the range of 101-102mA. The electrode resistance was then calculated by the Volt-Ampere method. The resistance values were from 26 to 43$m\Omega$.

3.2 Electrical features of the Post electrode

Brush electrode measurement was performed to compare the values of resistance. In the experiment, the voltage between the ends of the electrode was 2,6V. The Brush electrode current values were in the range of 70-78mA, which depended on the Brush electrode being pressed to the copper plate. The average current value was 74mA. Resistance was calculated from the mean values by the volt-ampere method. Its values were calculated as 35Ω.

Since the electrode is on the entire surface of the polymer, its resistance values are relatively high. Approximate resistance values could also be measured directly by the multimeter.

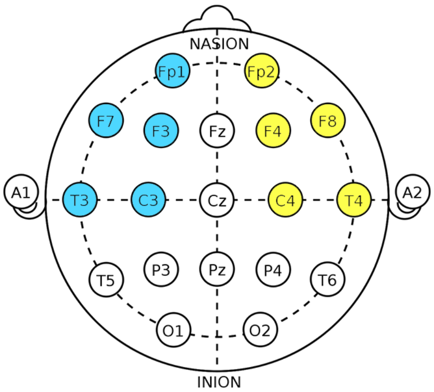

Figure 4: Electrode configuration

Figure 5: Skin irritation for short term use of dry electrodes. In the top: Post electrode with pins of 2 mm length; At the bottom: Brush electrode with pins of 5 mm length;

4 EEG data acquisition

The next step was to measure the EEG signals. An OpenBCI headset has been used to record signals. Signals were measured to compare the values and properties of signals obtained from two different electrodes.

Post and Brush electrodes were placed in the EEG headset at the same time to observe signal similarities under the same conditions. Two session signals were recorded during the experiment.

Based on the 10-20 configuration system, in the first session Brush electrodes were placed on the right hemisphere of the head and Post electrodes placed on the left hemisphere. In the second session, the electrode positions were reversed. Figure 4 shows the electrode positions of the experiment in 10-20 configuration system [7]. The positions on the left hemisphere are marked in blue and the yellow ones indicate the right. 10 electrodes were used for measurement, 5 Post and 5 Brush electrodes for each session.

The brain waves of a subject in the state of relaxation were recorded. The subject sat still in a comfortable position while playing the video. The subject watched the video was with a light concentration. Each session lasted 60 seconds. In the state of relaxation and light concentration, in the brain are created so-called alpha waves [8].

Figure 5 shows skin irritation. It can be seen that the Brush electrode leaves the skin reaction longer than the Post electrode. The pictures were captured after 10 minutes of EEG recording. After 30 minutes almost no reaction was seen in the Post electrode application area. In contrast, the Brush electrode left a visible sign after 30 minutes.

5 Signal comparison

In the Matlab programming environment, the signals were modified from the default format in which they are saved, to matrix for ease of evaluation. Then the alpha frequency bandwidth was filtered out of the signal. The alpha wave frequency is 8-12Hz. Alpha waves are created in a state of wakefulness when a person feels relaxed. By filtering this bandwidth some artefacts have been removed and only the clear brain signal from the subject's relaxation state has remained [8].

Individual hemispheres and brain parts are responsible for the various processes. Nevertheless, we can compare the values of signals in opposite positions. Artefacts or some brain activity with stronger pulses can also be occurred on opposite sides of the hemisphere simultaneously. In the Matlab programming environment, signals obtained from individual electrodes were compared. In the first step, the voltage levels on the both electrodes were compared. The comparison was always performed between the electrodes at the same positions on the opposite hemispheres.

The best comparison can be made on the forehead on the electrodes Fp1 and Fp2. This part transmits an electrical signal coming from visually evoked potentials and from eye movement. Therefore, comparing these signals is appropriate for the case in our experiment where the subject watched the video while recording the EEG.

The correlation of the raw signals from the first session was 0.92 on the Fp1 and Fp2 electrodes and after filtering the alpha bandpass, the correlation was 0.87. In the second session, the correlation between Fp1 and Fp2 signals was 0.98 and 0.97 on the alpha frequency band.

Figures 6 and 7, show the simultaneous signal plot of the Alpha wave EEG signal at electrodes Fp1 and Fp2 during the first and second session. From the EEG measurements, we can observe the signal sequence similarity on the electrodes Fp1 and Fp2.

In Figures 8 and 9, show the comparison of the frequency spectres. The Brush electrode signal is displayed in blue and the Post electrode signal is displayed in red. The Figures 8 represents frequency spectre of signal from the first session, where at position Fp1 there was the Brush electrode and at Fp2 was Post electrode. The Figure 9 rep-

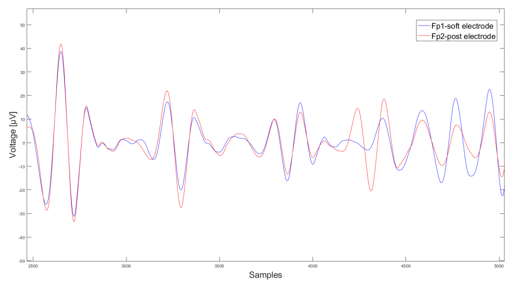

Figure 6: 10 seconds of Alpha waves of EEG signal on electrodes Fp1 and Fp2

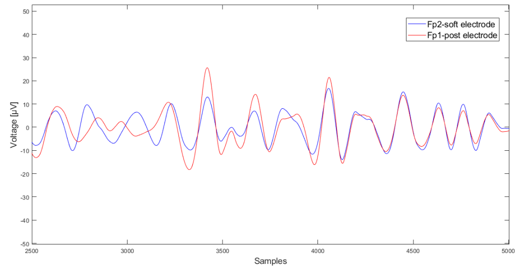

Figure 7: 10 seconds of Alpha waves of EEG signal on electrodes Fp1 and Fp2

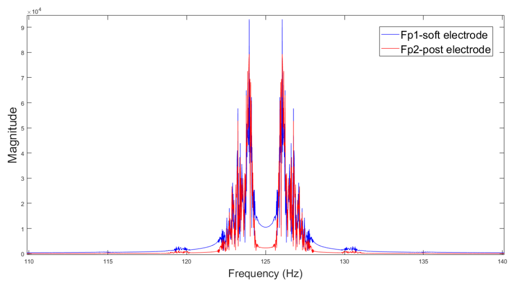

Figure 8: Session 1 - The frequency spectrum of alpha wave signal on electrodes Fp1 and Fp2

resent frequency spectre from the second session, where electrode positions were replaced.

The increase in frequency spectrum power on Brush electrodes was on average 20% in the first session. In the second, the increase with the use of Brush electrodes was on average 10%.

6 Results and Conclusion

Measurements of the electrodes electrical properties showed significantly higher Brush electrode resistance values. From the comparison of EEG signals, it can be stated that although the Brush electrodes is made of a conductive polymer and has a higher resistance, the signal values obtained by it are comparable to those of the signal obtained by the metal Post electrode. By connecting

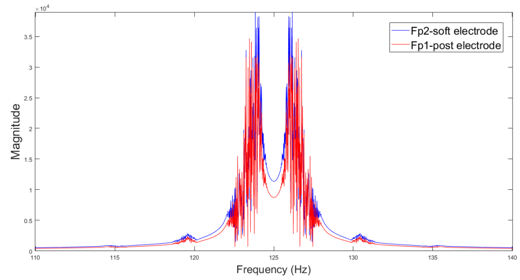

Figure 9: Session 2 - The frequency spectrum of alpha wave signal on electrodes Fp1 and Fp2

the electrodes to the OpenBCI hardware it has been shown that the use of a higher resistance electrode does not affect the measurement of the brain signal. The use of a suitable amplifier in the EEG headset smoothes the difference between electrode resistances.

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