A New Design of the Multi-channels Mobile and Wireless EEG System

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Abstract. Most researchers acquired EEG by using standard measurement system like NeuroScan system, which includes AgCl electrode cap, SynAmps Amplifier and Scan software to provide good reliability for the acquisition of EEG data. However, it is still not convenient for Brain Computer Interface (BCI) application in daily life because of needing conduction gels to contact skins and being wired, expensive and heavy. Moreover, the conduction gel will trend to be drying, so it does not suitable for long-term monitoring. In this study, we developed a mobile and wireless EEG system. The system consists of frond-end 16-channel dry electrode cap, a miniature low-power wireless portable circuitry, and a back-end program receiving events and digital EEG data simultaneously. We demonstrate the recorded EEG data have high correlations between from our system and from NeuroScan system.

Keywords: EEG, Brain Computer Interface, Mobile and Wireless EEG.

1 Introduction

To be practical for routine use in many cognitive experiments in the real operational environment, the data acquisition system must be non-invasive, non-intrusive, lightweight, battery-powered and easy to don and doff. Further, it must enable a full range of head, eye and body movements. The only possible brain imaging modality fulfilling these criteria is electroencephalography (EEG). Electroencephalography is a powerful non-invasive tool widely used for both medical diagnosis and neurobiological research because it can provide high temporal resolution in milliseconds which directly reflects the dynamics of the generating cell assemblies. EEG is also the only brain imaging modality that can be performed without fixing the head/body. Substantial research [1-5] has shown that many features of EEG dynamics index the current state of subject alertness, arousal and attention. However, data collection in most EEG studies requires skin preparation and gel application to ensure good electrical conductivity between sensor and skin. These procedures are time consuming, uncomfortable and even painful for participants since skin preparation

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usually involves abrasion of the outer skin layer. Repeated skin preparation and gel application for EEG may also cause allergic reactions or infections. Further, the signal quality may degrade over time as the skin regenerates and the conductive gel dries. Advance electrode designs are needed to overcome these requirements and complications of adhesive contacts between EEG electrodes and the skin surface before routine EEG monitoring can be feasible in real-world environments. In this study, we developed a mobile and wireless EEG system. The system consists of frond-end 16-channel dry electrode cap, a miniature low-power wireless portable circuitry, and a back-end program receiving events and digital EEG data simultaneously. We demonstrate the recorded EEG data have high correlations between from our system and from NeuroScan system.

2 Mobile and Wireless EEG System Components

Figure 1 shows our proposed 16 channel mobile and wireless EEG system consisted of three parts (1) 16-channel dry electrode cap, which is made of comb-like gilt on every dry electrode. The design of dry electrodes avoids the bad contact in hairy site and can fit the skull shape so that the conductivity is good enough to acquire EEG data. (2) a miniature low-power wireless portable circuitry, which including high-pass filters over 0.5Hz, amplifiers, a 16-to-1 multiplexer, a 12-bit analog-to-digital (A/D) converter, a power management circuit, and a wireless transmission circuit. The microprocessor filters 60Hz noise digitally. The amplifiers are designed about 5500 times. The power operates at 3V for low-consumption. The cut rate of all channels is 2k Hz. The A/D sampling rate is 125Hz for one channel. Moreover, the UART baud rate of Bluetooth is 115200 bit per second. Our proposed system can measure input voltage range about 272.7 uV compared to reference potential. (3) a back-end program, which simultaneously received events of experience and EEG digital data transmitted from Bluetooth. The program plotted the analog signal to display and recorded all data to a file with txt format.

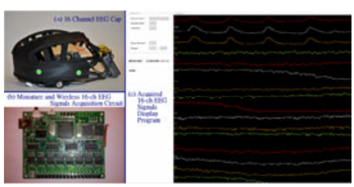

Fig. 1. Components of the proposed 16 channel mobile and wireless EEG system

16-channel Dry Electrode Cap. The cap we used is shown in figure 1(a) which is consisting of 16 metal-made electrodes to acquire EEG data from cortex. We utilize nine probes (3 x 3 arrays) with metal material and spring-loaded features to form each dry electrode. Utilizing the dry electrode on the scalp can directly acquire the EEG signal and does not need to use conductive gels. Further, the signal quality may degrade over time as the skin regenerates and the conductive gel dries. Advance electrode designs are needed to overcome these requirements and complications of adhesive contacts between EEG electrodes and the skin surface before routine EEG monitoring can be feasible in real-world environments. In addition, the dry electrode can also apply on the hairy site area to overcome the interference of acquisition problem via bushy hairs. The placements of total 16 dry electrodes are followed by the international 10-20 system.

Miniature Low-power Wireless Portable Circuitry. Figure 1(b) shows the development of the proposed miniature, portable and wireless EEG-signal acquisition unit, which combining high-pass filters over 0.5Hz, amplifiers, a 16-to-1 multiplexer, a 12-bit analog-to-digital (A/D) converter, power management circuit, and wireless transmission circuit into one. Instrumentation Amplifier (IA) which has a high common-mode rejection ratio (CMRR) is good for the applications that the signal of interest is represented by a small voltage fluctuation superimposed on a voltage offset. The operational amplifiers are designed about 5500 times and filter the signals over 0.5 Hz. Next, the 16-channel input signals sequentially pass a 16-to-1 multiplexer with 2k-Hz cut rate every channel. The Analog-to-Digital (A/D) converter samples the data at 125-Hz rate all channels. The digital data are saved in buffers of a microcontroller and then are carried to wireless transmission circuit through UART. The baud rate of Bluetooth is 115200 bit per second. In the unit, The power management circuit operates at 3V for low-consumption and has recharge function. Thus, our proposed acquisition circuit can monitor input voltage range about 272.7 uV compared to reference potential and lossless the EEG signal of interest.

EEG Data Acquisitions and Signal Processing. Figure 1(c) is the display of 16 channels EEG signal acquisition. A back-end record program, which simultaneously received events of experience and EEG digital data transmitted from Bluetooth wireless module. The program display the digital-to-analog signal on a frame in real-time and can also record all channel data to a file with TXT file format.

3 Comparison Experiments Design and Results

For evaluating the data acquisition performance and feasibility of the proposed 16 channel mobile and wireless EEG system. We apply two kinds of testing experiments to the proposed system. First testing is using the simulation data generated by a function generator and the other one is real EEG signals acquisition comparison between our proposed wireless EEG system and the commercial NeuroScan system.

Simulation Data Testing. Here we utilized the function generator to produce 5 Hz input signals and feed the simulated signals into one channel of the acquisition circuit. The record data received by the display program was compared to the standard sin wave generated by MATLAB. We generated the arbitrary simulated signals as the special EEG features for the system comparison. In Figure 2, the blue line is showed the arbitrary simulated signals generated by function generator and red line is the acquisition performance from our development of miniature low-power wireless portable circuitry. Although the sampling size of our record data is smaller than of the simulated wave, it’s no influence that the special features of Signals recorded by our system are highly correlated to the simulated signals via function generator.

Then, we generated four different frequency bands (5, 10, 15 and 20 Hz) simulated signals to test the comparison results. As shown in figure 3, after doing Fast Fourier transform, we can easily see that the major peak of the high power is consisted and matched in each frequency of the generated signals.

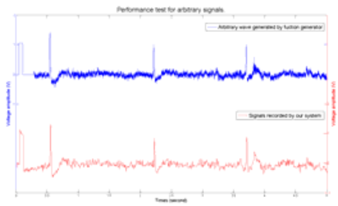

Fig. 2. Comparison Results of the Simulation Data Testing in Time Domain

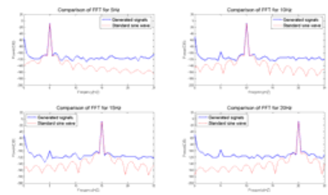

Fig. 3. Comparison Results of the Simulation Data Testing in Frequency Domain

Real EEG Data Acquisition Testing. In this section, we acquire the real EEG signals from five different channel placements (Fp1, T3, Cz, T4, and Oz) in the international 10-20 system and show the comparison results between our proposed wireless EEG system and the commercial NeuroScan system. Table 1 shows the average correlations in time domain of the EEG signal fluctuations between our proposed wireless EEG system and the commercial NeuroScan system. It is clear to see that the correlations can reach 88.34%.

Table 1. Correlation Results of the Real EEG Data Acquisition in Time Domain

Placement	10-s Max correlation (%)	10-s Average correlation (%)
FP1	96.75	93.01
T3	90.46	86.80
CZ	94.48	91.82
T4	90.08	88.19
OZ	88.98	81.87
Average	**92.15**	**88.34**

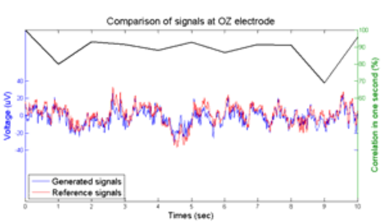

Fig. 4. Oz Signal Fluctuation between the proposed mobile and wireless EEG (Blue line) and commercial NeuroScan System (red line) and the correlation results (black line)

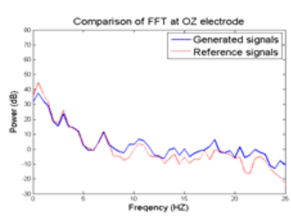

Fig. 5. Frequency Fluctuation in Oz channel between the proposed mobile and wireless EEG (Blue line) and commercial NeuroScan System (red line)

Here we plot the Oz signal fluctuation as the sample case shown in figure 4. It shows 10 sec results. EEG signal acquired from our proposed mobile and wireless EEG system is showed in blue line, red line is acquired by the commercial NeuroScan system, and the top black line shows the correlations of the 1 sec EEG signal fluctuation. Almost the correlations are higher than 85%.

Table 2 shows the average correlations in frequency domain of the EEG signal fluctuations between our proposed wireless EEG system and the commercial NeuroScan system. It is clear to see that the correlations can reach 95.44%.

Table 2. Correlation Results of the Real EEG Data Acquisition in Time Domain

Electrode place	10-s Max correlation (%)	10-s Average correlation (%)
FP1	98.36	96.53
T3	98.41	94.89
CZ	97.18	89.08
T4	98.26	95.44
OZ	98.42	88.69
Average	**98.13**	**92.93**

We also plot the frequency fluctuation of the Oz signal after FFT as the sample case shown in figure 5. It shows the 10 sec average correlation result. Blue line is the result of the proposed mobile and wireless EEG and red line is the result of the commercial NeuroScan System. Maximum correlation in 10 sec can reach 98.42% and average correlation in 10 sec can be 88.69%.

4 Discussion and Conclusion

According to the experimental results, the data acquisition performance of our proposed 16-channel mobile and wireless EEG is highly correlated with the commercial EEG system (NeuroScan). The experimental results of this study also provides a new insight into the understanding of complex brain functions of participants actively performing ordinary tasks in natural body positions and situations in operational environments. Such data would be difficult or impossible to obtain in a standard EEG laboratory where participants are asked to limit their eye blinks, teeth clinching or other head/ body movements. These experimental results may also be applied in future studies to elucidate the limitations of normal human performance in repetitive task environments and may inspire more detailed study of changes in cognitive dynamics in brain-damaged, diseased or genetically abnormal individuals. The proposed system has many potential applications in clinical research and practice in such diverse fields as neurology, psychiatry, gerontology and rehabilitative medicine.

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