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A Simulation Study on a Single-Unit Wireless EEG Sensor

Bo Luan¹ and Mingui Sun^{1,2}

¹Department of Electrical & Computer Engineering, Neurosurgery University of Pittsburgh, Pittsburgh, PA 15213, USA

²Department of Neurosurgery University of Pittsburgh, Pittsburgh, PA 15213, USA

Abstract

Traditional EEG systems are limited when utilized in point-of-care applications due to its immobility and tedious preparation procedures. We are designing a novel device named single-unit wireless EEG sensor to solve these problems. The sensor has a size similar to a U.S. penny. Four electrodes are installed within a 20mm diameter cylinder. It can be applied to scalp in seconds to amplify, digitize and wirelessly transmit EEG. Before the design and construction of an actual sensor, in this paper, we perform a set of simulations to quantitatively study: 1) can the sensor acquire EEG reliably? 2) will the selection of sensor orientation be an important factor to influence signal strength? Our results demonstrate positive answers to these questions. Moreover, the signal sensor acquired appears to be comparable to the signal from the standard 10-20 system. These results warrant the further design and construction of a single-unit wireless EEG sensor.

Keywords

Electroencephalography (EEG); Single-unit EEG sensor; Spherical head model

I. Introduction

Electroencephalography (EEG) measures the potential on scalp resulting from neuron activities within the brain. However, the current method to apply EEG electrodes on scalp is time-consuming. Also, the traditional EEG electrodes require wire connections to the amplifier which is inconvenient for the subject. These problems highly limit the use of EEG in point-of-care applications. Therefore, we are working on developing a wireless single-unit wireless EEG sensor. This cylindrical sensor has a 20mm diameter and a 10mm height. The outer boundary of the sensor, which is made of stainless steel, is segmented into four identical, but electrically isolated quarter-arc shape electrodes. One pair of electrodes at opposite positions is taken as recording electrodes and the pair is connected together as ground. These two pairs of electrodes can be reconfigured to measure the electric potential difference in two different directions. Usually one of the configurations can capture a bigger potential difference than the other if its direction aligns with the direction of potential gradient in that local area. A detailed description of our envisioned sensor is provided in [1].

There have been no previous studies that implemented four quarter-arc shape electrodes in such a small space. Therefore, two questions arise concerning the feasibility of four design: 1) can the sensor composed of compactly-spaced electrodes acquire EEG reliably? and 2) will the orientation of the sensor be a factor to influence the signal strength? To quantitatively investigate these questions, in this paper, we carried out a set of simulations.

II. Simulation Method

A model to simulate the generation of electric potential measured at the scalp has been established where the head and electrical source are modeled as a four-layer conductive sphere and a current dipole, respectively. The spherical head model includes four concentric layers representing the brain, cerebrospinal fluid, skull and scalp, each with its own conductivity and thickness [2]. The current dipole is characterized by its location, strength and orientation. The single-unit sensor is modeled as four arcs situated on the surface of the sphere, as shown in Fig. 1. The potential on the arc is estimated by averaging multiple points of potential values covered by the arc.

In this simulation, for each dipole, a large number of sensors are randomly generated on the surface of the sphere model. The uniform probability distribution is utilized in this process. A fast computation method is used to calculate the electrical potential on a spherical model surface [3]. The potential differences for the two configurations are calculated. The histogram of these differential potentials is used to display the distribution of these potentials. The above process is repeated for a large number of dipoles. The locations of these dipoles are distributed uniformly within a selected shell in the head model, and their orientations are also randomized. The sum of all the histograms according to all the dipoles is plotted as an overall indicator of the potential distribution recorded by the sensor. The percentage above a given threshold in this plot is used to evaluate the ability of the single-unit sensor in acquiring EEG signal.

III. Results

The parameters of the head model used in this simulation are listed in Table I. The radius of the head was 9 cm. During the simulation, current dipoles were placed uniformly in a shell which was assumed to be the gray matter layer within the brain. According to Kiourti's five-layer head model, the thickness of this layer was set to 14 mm [4]. The average strength of the dipole moment M was determined by $M = s_i \times 525$ (nA/mm), where s_i is the cortical surface area activated due to activities of neuronal population i , and 525 nA/mm is the average surface current density [5]. Here we assumed that the area of activation was uniformly distributed in three different ranges: (0-10cm²), (0-15cm²), (0-20cm²).

For each dipole, 1,000 single-unit sensors were randomly generated on the sphere surface. 1,000 dipoles were generated and the overall histogram of the potential difference was computed. In the simulation of our single-unit sensor, the bigger potential difference among the two pairs of outputs is saved for all generated sensors. In addition, one potential difference was also randomly selected among the two pairs.

To compare the EEG signals recorded by the four-arc electrodes with the conventional EEG recording, the electrodes in a standard 10-20 system were also modeled. For each dipole, two surface points representing two adjacent electrodes were created on the surface of the sphere and the potential difference between adjacent electrodes was computed. The inter-electrode distance was set to 45mm [6]. 1,000 bipolar recordings were calculated for each dipole.

Fig. 2 shows the distribution of potential differences of single-unit sensor model comparing to the standard 10-20 system model considering cortical surface area range (0-15cm²). The center shoot for subplots (b) and (c) demonstrates relative high occurrence of small values. The sensor model selecting bigger potential differences among two pairs shows fewer occurrences of smaller values. In Table II, we list detailed comparison between the single-unit sensor model and the standard 10-20 system model. This table compares the percentage of potential difference larger than certain threshold among all recorded potential differences. At either 0.5 μ V or 1 μ V threshold, single-unit sensor selecting bigger potential differences shows comparable performance as the 10-20 system. The choice of thresholds was based on the measurement resolution of today's EEG amplifiers. For example, Texas Instruments ADS1299 analog front-end amplifier has 24-bit resolution, which allows it to measure as accurate as about 0.3 μ V.

IV. Conclusion

Our simulation study demonstrated that the sensor with closely-spaced electrodes can acquire EEG. The study further demonstrated when selecting certain sensor configuration, the quality of acquired signal is similar to that of the standard 10-20 system. The results and conclusion from this simulation study warrant further study and construction of the single-unit wireless EEG sensor.

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REFERENCES

1. Luan B. A feasibility study on a single-unit wireless EEG sensor. IEEE 12th International Conference on Signal Processing, 2014:2282–2285.
2. Stock CJ. The inverse problem in EEG and MEG with application to visual evoked responses. 1986
3. Sun M. An efficient algorithm for computing multishell spherical volume conductor models in EEG dipole source localization. IEEE Trans. Biomed. Eng. Dec.1997 44:1243–1252. [PubMed: 9401224]
4. Kiourti A, Nikita KS. Design of implantable antennas for medical telemetry: Dependence upon operation frequency, tissue anatomy, and implantation site. International Journal of Monitoring and Surveillance Technologies Research (IJMSTR) 1.1. 2013:16–33.
5. da Silva, FL. EEG-fMRI. Springer; Berlin Heidelberg: 2010. EEG: Origin and measurement.; p. 19-38.
6. Niedermeyer, E.; da Silva, FL. Electroencephalography: basic principles, clinical applications, and related fields. Lippincott Williams & Wilkins; 2005.

Fig. 1.

Volume conduction model used in this study. The four green arcs on the surface of the sphere represent four electrodes. The black dot represents the location of the dipole. The red line pointing from black dot to sphere surface represents the dipole moment. The color on the surface of the sphere represents the calculated strength of the potential.

Fig. 2.

The potential distribution for (a) our proposed sensor selecting bigger potential difference among two pairs; (b) the sensor randomly selecting one pair of electrodes among the two; (c) Bipolar recordings acquired from two adjacent electrodes in the standard 10-20 system.

TABLE I

Head Model Parameters Used in the Simulation

	Scalp	Skull	CSF	Brain
Radius (cm)	9	8.52	7.80	7.56
Conductivity (S/m)	0.33	0.0042	1.0	0.33

TABLE II

Comparison of Single-Unit Sensor and 10-20 System

Surface Area Range	Voltage Threshold (μV)	Sensor Max Difference (%)	Sensor Random Difference (%)	10-20 System Difference (%)
(0-10cm ²)	0.5	84.17	69.58	83.51
	1	69.92	51.99	72.91
(0-15cm ²)	0.5	88.41	76.01	87.44
	1	77.66	61.38	78.84
(0-20cm ²)	0.5	91.16	80.56	90.08
	1	82.59	68.19	82.87