

Development of a transcranial direct current stimulation (tDCS) device based on polarity interchangeable electrodes

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Abstract.

BACKGROUND: Transcranial direct current stimulation (tDCS) is a noninvasive brain stimulation technique that can help modulate cortical excitability by transmitting direct current (DC) between a pair of scalp electrodes. To date, most studies on tDCS have been relatively short-lived, and the DC stimulations only lasted a few minutes. Conventional tDCS devices usually have some problems such as needing a lot of patches and lead lines.

OBJECTIVE: Since conventional tDCS devices are unsuitable for use in long-term stimulations, we developed a new tDCS which can easily be used by unskilled persons.

METHODS: We developed a new tDCS device that does not have lead lines for tDCS electrodes and has a simple structure.

RESULT: This device can achieve stimulation with polarity interchangeable DC without physically swapping the anode and cathode. The performance of the proposed device was verified through an experiment.

CONCLUSION: The developed tDCS device can contribute to long-term research as it uses neuroelectric stimulation.

Keywords: Transcranial direct current stimulation (tDCS), interchangeable electrodes

1. Introduction

Two methods of non-invasive electromagnetic stimulation of the human brain have dominated research studies in the past few decades: transcranial magnetic stimulation (TMS), which activates axons via short-pulsed stimulation and thereby eliciting new action potentials; and transcranial electric stimulation, which is the more predominant method [1]. Although the effect of transcranial direct current stimulation (tDCS) is similar to that of repetitive TMS (rTMS), tDCS has garnered attention in the neurosciences because of its advantages over rTMS, including better mobility, increased safety, and lower cost [2–4].

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Recently, transcranial stimulation paradigms have received increased interest as tools for modulating cortical excitability and behavior in diverse clinical settings and experimental conditions. tDCS is a paradigm that holds particular promise in both settings as it is noninvasive, painless, and tolerated well [1]; it is capable of modifying neuronal resting membrane potentials and the level of spontaneous neuronal firing in the area of stimulation as well as in interconnected neural networks [5]. tDCS has shown to have beneficial therapeutic effects for various diseases such as stroke, refractory epilepsy, chronic depression, drug cravings, fibromyalgia, and traumatic spinal cord injury [6–12].

The behavioral effects from these studies were relatively short-lived, and the direct current (DC) stimulations only lasted a few minutes. Several studies have shown that early evidence for spaced sessions might increase the durations of these behavioral effects to several weeks in both healthy controls and patients [9,13,14]. Recent advances in the field have renewed and expanded interest in long-term DC stimulations and spaced sessions; thus, further research is needed. However, most of the conventional tDCS devices are hard to use for unskilled operators because they need to attach a lot of patches and lead lines to the subjects, which requires precision and experience. Therefore, there is need to develop a tDCS device that can be easily used by everyone.

In order to overcome this operational issue, we developed a new polarity interchangeable tDCS device. This device has a simple structure to enable easy usage, and it can stimulate polarity interchanges using an interchange circuit unit. The performance of the proposed device is verified through an experiment, where the output current is measured.

2. Theory and methods

2.1. Theory of tDCS

The application of tDCS produces polarizing currents, and the effects of weak polarizing currents are critically dependent on the strength and the duration of the applied current [1]. DC stimulation is generally described in terms of the current density. Current density is defined as the electric current flow per unit cross-sectional area; then, the current density J is defined as:

$$J = \frac{I}{A}, \quad (1)$$

where A is a homogeneous area, and the electric current I is amount of charge that is flowing through A per unit time [15]. The total charge is given by the product of the number of pulses with electric impulses n , intensity I_p , and duration τ . The total charge corresponding to the n pulses is given as:

$$Q_t = n\tau I_p. \quad (2)$$

Thus, when A is the active area of the electrode for the total charge, it can be demonstrated that the charge density for each pulse is as follows, with σ being the total charge:

$$\sigma = \frac{\tau I_p}{A}. \quad (3)$$

Since the total charge and active area are inversely proportional to each other, the electrode size of the tDCS device that is commonly applied at the forehead needs a larger area. Besides, it is very important to decide on not only the active area but also the current direction because tDCS induces polarization of the brain tissue. The current direction for the tDCS is determined by the positions of the anode and cathode.

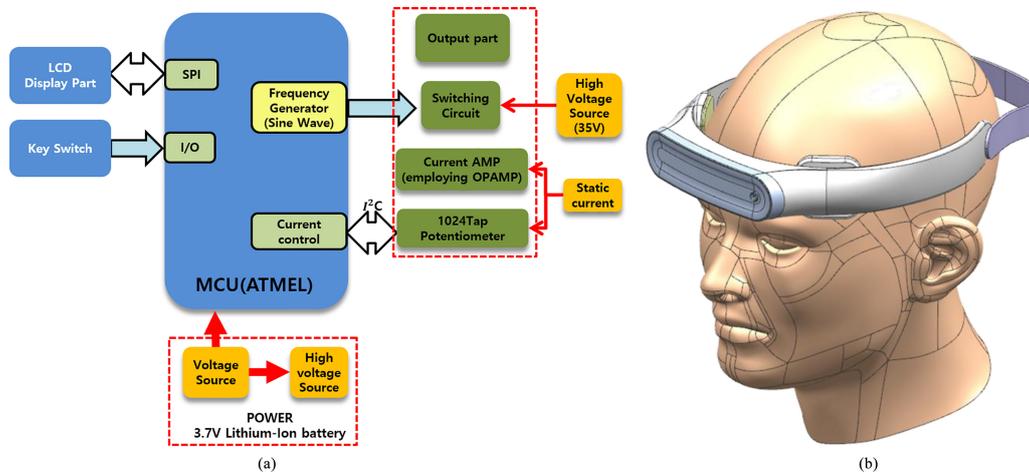


Fig. 1. Schematic of the proposed tDCS device: (a) signal and power flowchart, and (b) mode of attachment of the proposed tDCS device.

2.2. Concept of the proposed tDCS device

Figure 1 shows the conceptual schematic of the proposed tDCS device. The device consists of three main parts: display, microcontrol unit (MCU), and power supply. The proposed device is operated by a 3.7-V lithium-ion battery, and the liquid crystal display (LCD) is represented by the serial peripheral interface (SPI) of the MCU. The main printed circuit board (PCB) and power PCB simulate the direct current by the input and output (I/O) signals.

Figure 2 shows the circuit diagram of the main PCB. It consists of the MCU, power unit, battery unit, light emitting diode (LED) unit, and Wi-Fi unit. The power unit operates by receiving 3.7-V input from the battery. Then, the MCU controls the LED and Wi-Fi units, and DC is generated at the I/O pin of the MCU connected to the power PCB. Figure 3 shows the circuit diagram, layout, and assembled PCB of the power unit. The power unit consists of a constant current chip, connector, switch chip, and so on. The constant current chip operates by receiving a constant voltage through the switch and produces output currents at three steps, namely 0.6 mA, 1.2 mA, and 1.8 mA. The switch controls the on and off for receiving the signal of 3.3–5 V through the connector. The layout has a 6 mm wire gauge, two printed layers, 1.6 T, and a finished PCB size of 34.92×34.92 mm.

2.3. Implementation of the polarity interchangeable tDCS

Figure 4 shows the circuit diagram, layout, and assembled PCB of polarity interchangeable PCB. The polarity interchange circuit works on 3.3–5 V, and the output signal can interchange the separating anode and cathode to operate the switch according to the signal. The layout has a 6 mm wire gauge, two layers, 1.6 T, and a finished size of 34.92×34.92 mm.

2.4. Manufacturing of the proposed tDCS device

A combined layout is designed from the circuits. Figure 5a shows the layout of the combined main control equipment. The layout has 6 mm of wire gauge, 2 layers, 1.6 T, and is of the size of $100 \text{ mm} \times 35 \text{ mm}$. The MCU, crystal, LED, Wi-Fi module, regulator, and switch are located at the front side, and

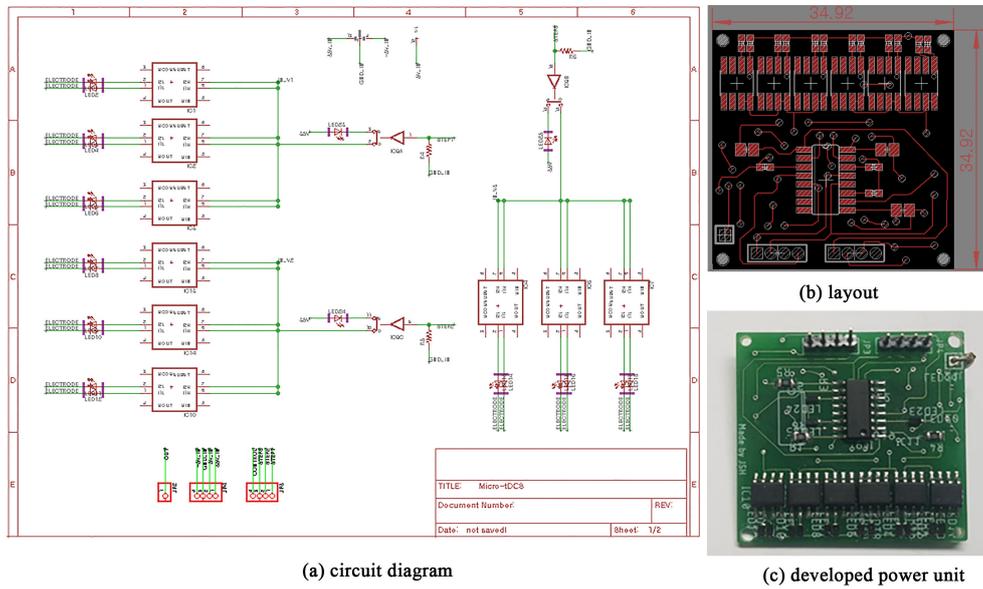


Fig. 3. Schematic of the power unit.

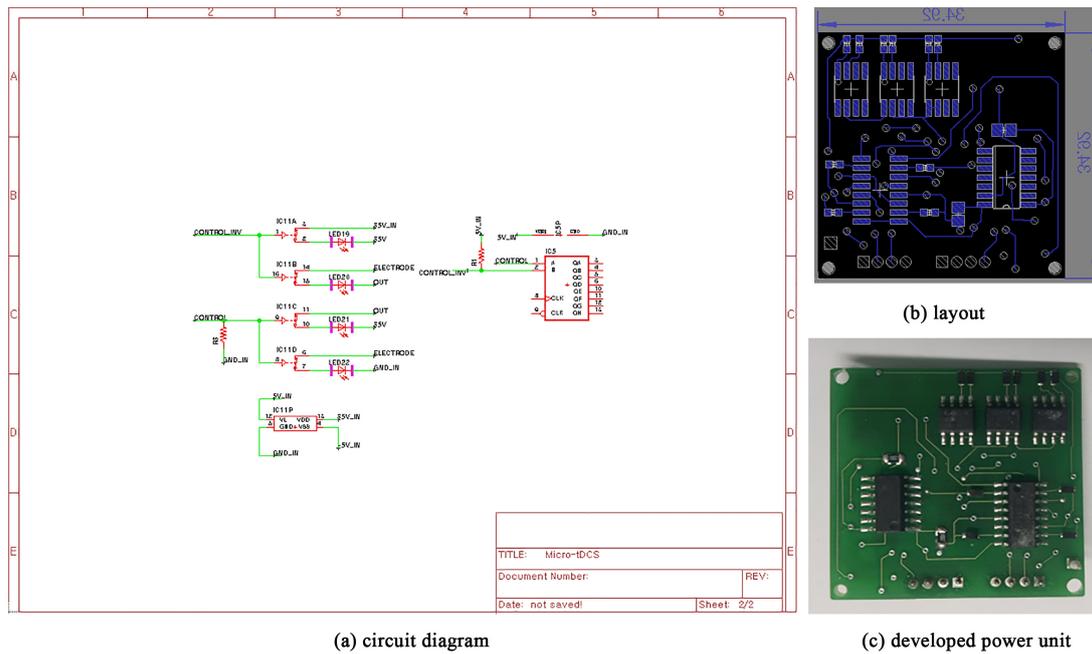


Fig. 4. Schematic of the polarity interchange PCB.

the battery, connector, and battery charging IC chip are located at the back. Figure 5b shows the design of the proposed tDCS device. The final design had a fixed band and was easy to attach to a stimulation pad. The proposed device has an LED display at the center in the front, the power button is at the center on the top of the device, and the DC stimulation pad is at the face and it touches the forehead.

Table 1
Accuracy of the output current

	Ideal value	Average value	Mean of error	STD of error
Current step1	600 μ A	599.9 μ A	0.0120%	0.0076
Current step2	1200 μ A	1201.0 μ A	0.0863%	0.0041
Current step3	1800 μ A	1801.2 μ A	0.0667%	0.0036

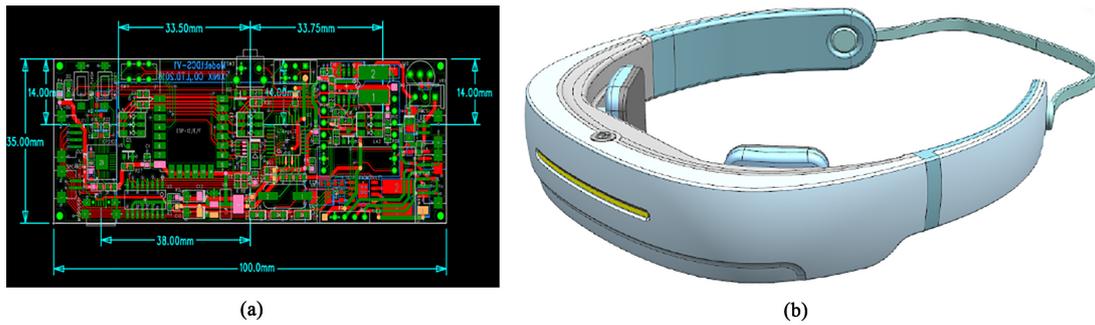


Fig. 5. Proposed tDCS device: (a) layout of the main control PCB, and (b) design of the device.

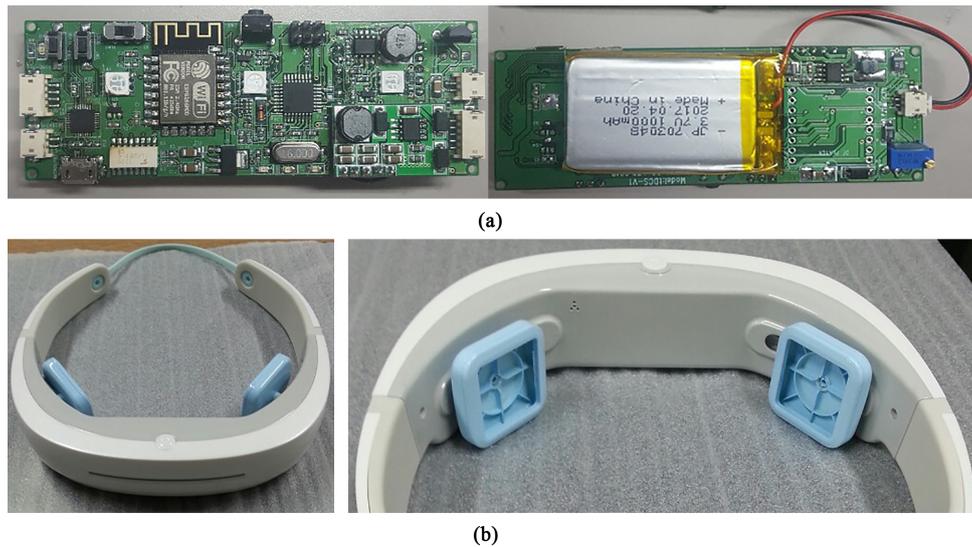


Fig. 6. Developed tDCS device: (a) main controller, and (b) assembled device.

3. Results

3.1. tDCS hardware system

Figure 6 shows the assembled main control PCB. Figure 6a shows the developed main controller using the designed PCBs of size 100 mm \times 35 mm, and a 3.7 V lithium-ion battery at the backside. The LED light at the front side will turn on and off to indicate the working process. Figure 6b shows the developed tDCS device, which has the size of approximately 200 mm \times 190 mm \times 40 mm. As can be seen in Fig. 6b, the case of the DC stimulation pad is positioned such that it touches the forehead. The DC stimulation

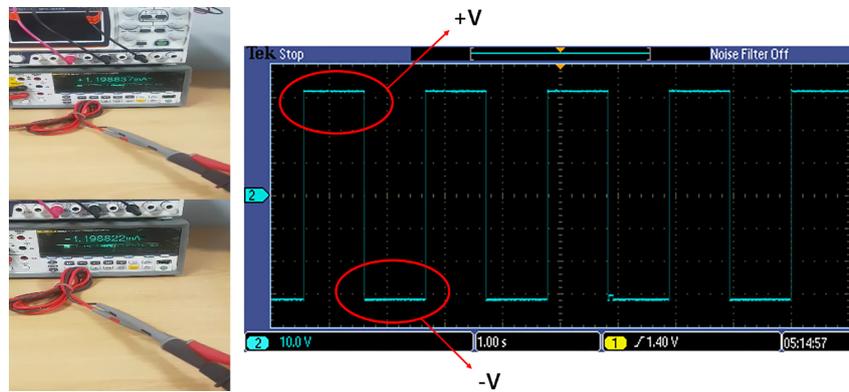


Fig. 7. Result of the current interchange.

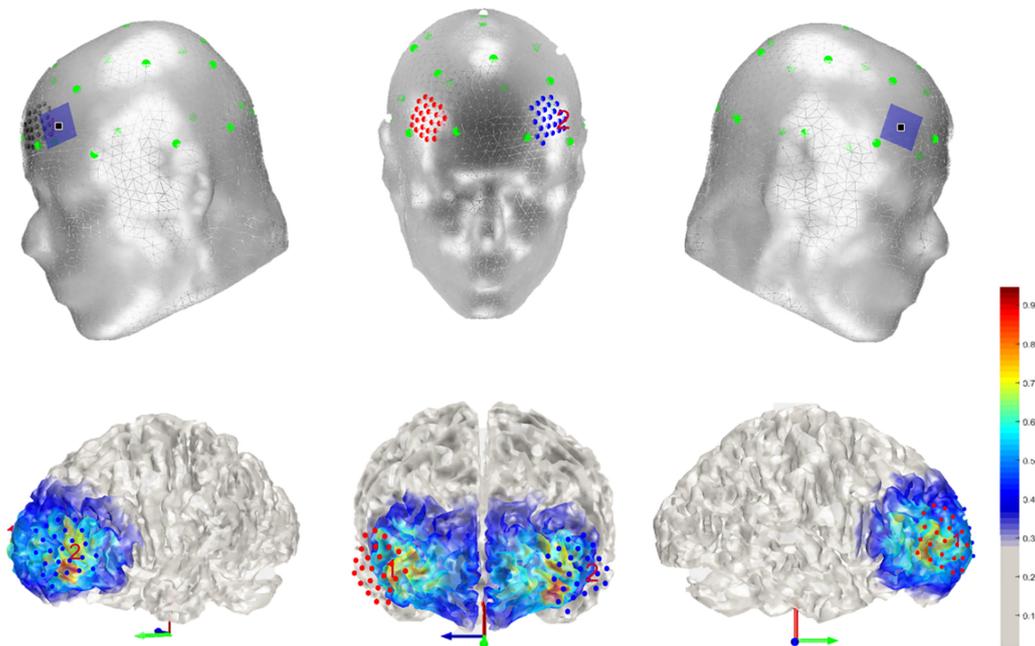


Fig. 8. tDCS simulation result from COMETS software. The first column shows the electrode location and shape (3 cm \times 3 cm) for brain stimulation. The second column shows the 3D cortex imaging, including the stimulated areas.

pad can be easily attached using the pad case and it is easy to move in the horizontal direction. The customized electrode is of a rectangular shape of the size 3.0 cm \times 3.0 cm. For enable current flow and high conductivity, the electrode was made of dimethyl, methylvinyl siloxane, dimethylvinly-terminated, carbon black, dimethyl siloxane, hydroxy-terminated, and dimethylcyclosiloxanes.

3.2. Evaluation of tDCS current stimulation

In order to evaluate the performance of the developed tDCS, the output current was measured over 25 times in the experiment with the various conditions. The accuracy of the output current is presented in Table 1. The result shows very high accuracy and the total current error is extremely low (0.0589%).

Figure 7 shows the features of the proposed tDCS system, where interchangeable electrodes with one physical electrode can also be used. When the ideal current is ± 1.2 mA, the developed tDCS device outputs a current of ± 1.1988 mA and it successfully demonstrates the interchanging voltage.

3.3. tDCS simulation for forehead stimulation using COMETs software

In order to understand the simulated area on the brain cortex, COMETs software was employed to show 3D stimulated images. The tDCS electrode has a rectangular shape of the size $3.0\text{ cm} \times 3.0\text{ cm}$. The area stimulated by the current flow was estimated by the COMETs software (Fig. 8).

4. Conclusion

In this study, we developed a new tDCS device that can be worn with polarity interchangeable electrodes. The developed device had a minimized main controller, 3.7 V battery, and horizontal movable case of a stimulation pad. The performance of the proposed device showed extremely high accuracy (the STD of error was under 0.01%). A very low STD of error implies that the proposed device has the potential for simultaneous use of EEG and the tDCS system because the proposed system can enhance the SNR of the EEG signal during the tDCS stimulation on the brain.

Since the developed device does not need any lead lines for the electrode and is easy to wear, we expect that it can be easily used by not only experts but also unskilled persons. Moreover, it can stimulate the polarity interchangeable DC without moving the position of the anode and cathode. As a result, the developed tDCS device can contribute to the research by using tDCS stimulation in spaced sessions and long-term stimulation.

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Conflict of interest

None to report.

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