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A remote constant current stimulator designed for rat-robot navigation

Xi Chen, Kedi Xu*, Shuming Ye, Songchao Guo, Xiaoxiang Zheng

Abstract— **In this paper, a remote stimulator is developed for rat-robot navigation based on the technique of Brain-Computer-Interface (BCI). The stimulator can output constant current from 0 to 1000 μA, which overcome several shortages of our previous constant voltage stimulator. The constant current stimulator consists of four major components, including power supply, micro control unit (MCU), constant current source and bluetooth transceiver for downloading stimulation commands. The stimulator has a weight of about 20g and size of 32mm*25mm*6mm. It has five channels of stimulation, which are connected with implanted microelectrodes in rat brain. The electrical parameters were characterized on three rats with different recovery time after brain surgery. Increasing current stimulations were applied on the dorsolateral periaqueductal gray (dlPAG) area to prove the effect of current stimulation on rat behavior.**

INTRODUCTION

Brain-Computer-Interface (BCI) provides a new approach to establish a direct interaction between animal's brain and computer or machine [1-3]. One of the substantial applications of BCI technology is the bio-robot. Through the implantation of microelectrodes into specific regions of animal brain and the application of certain electrical stimulations, the animal can finish several kinds of instructions, for example walking forward, stop, and turn left and right. In recent years several kinds of bio-robots have been implemented, including pigeons [4], rats [5-8], sharks [9] and so on.

Electrical stimulation is one of the fundamental tools in bio-robot [10]. At beginning, the cable connections between the stimulation instrument and animal brain limited the animal's free-movement may cause entwisting and breaking of the cables. In order to solve this problem, telemetry system has been developed to deliver stimulation signals [11][12]. In our previous research, a remote constant voltage stimulator was designed to navigate the rat-robot pass through complex environment [8]. However, this stimulator system still had some deficiencies:

(1) The stimulation system was based on constant voltage source and stimulated by bi-directional voltage pulse, whose amplitude was decided by software and the value is constant. As we know, the animal's reaction to electrical stimulation has been proved to be directly related to the current that flow through the animal's brain [5]. However, the relationship between stimulation voltage and current is not linear correlation due to the changes in resistance of brain tissue. The polarization voltage, capacitive reactance and inductance of rat's brain will contribute to the nonlinearity of the current. Thus, it's hard to get the accurate current value by application the stimulation through voltage.

(2) Moreover, different individuals don't have the same resistance due to the individual difference of rats and the manufacture of different microelectrodes, thus an effective parameter of one individual may not work well on another. Even on the same implanted microelectrode, the resistance may also change through the whole experimental period. After a long time, three months for example, the microelectrode will be oxidized or encased by connective tissue, which will finally result in changes of resistance. Thus the voltage needs to be changed to ensure the same effect on the animal.

(3) Hardware design could be improved to consume less power of each stimulation and decrease the size and weight of whole stimulator. Less power consumption could reduce the battery number from two 3.7V Li - ion batteries to one, which could further reduce the system weight. Lighter board will help reduce the tiredness after a long time of carrying.

In this study, a constant current stimulator was designed to replace previous voltage stimulator with less power consumption and weight, which is more suitable for the navigation of rat-robot. The former work in [8] was developed by same group of QAAS, which described a concept of constant current stimulator. However, it cannot provide a precise current value and didn't give reflection of rats when given stimulation of different level. So QAAS still tried to develop a stimulator of lower power consumption and higher reliability for further study.

METHOD

The whole system consists of three parts: the main board, Bluetooth receiver and a personal computer (PC). The PC is used as the main controller using an integrated software interface. Two Bluetooth modules are used for wireless

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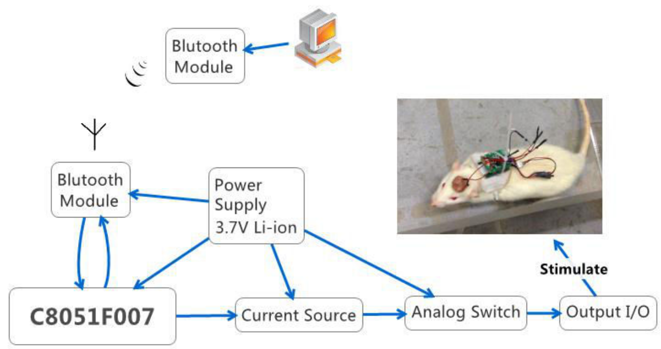
communication. On the PC side, PC gives a series of parameters through USB to UART module. One the backpack side, the MCU has a high speed Bluetooth receiver which can receive parameters and transfer them to the main board. The main board is used to convert the parameter to a certain current pulse and choose a channel to stimulate the animal through an output connector.

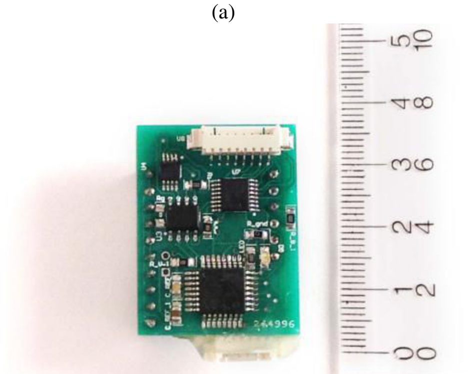
A. *Hardware*

Backpack

A complete view of the backpack is given in Fig.1. The backpack includes mainboard and Bluetooth receiver. Both boards use surface-mounted devices (SMD 0805 package). The total weight is about 20g and the size of the mainboard is 32mm*25mm*6mm. The rat also wears a vest which can help to keep the backpack steady.



(a)



(b)

Fig.1 (a) shows the circuit schematic diagram of the micro-stimulator. (b) is an actual photo of the backpack. The backpack connects with a bluetooth module and is kept on rat's back.

Mainboard

The power supply of the system use 3.7V Li - ion battery as the original power. One battery can provide enough voltage value with the help of DC-DC boost converters. Considering the stimulating current will not over 1mA and the resistance of the microelectrode is normally around 20 kΩ[13], the peak - peak Value of power supply will not over 20V. The system also gives biphasic rectangular pulses to prevent the brain from accumulating of electrical charges, which will cause permanent damage of brain. According to these demand, we choose TPS61040 as the DC-DC boost converter. TPS61040 has the advantage of low quiescent current, low shutdown current and high efficiency, which will help to boost the input voltage to ±10V with circuits design. The ±10V voltage will be used for amplifier in the constant current source and analog switch in the output module. The MCU will be supplied by low dropout regulator (LDO), which will convert the input voltage into 3V with ultralow noise, very low dropout voltage and fast start-up time.

The Mixed-Signal FLSH MCU (C8051F007) is the main processor of the stimulator in the backpack. The processor has the advantage of high speed (25 MIPS at 25MHZ), small size (9mm*9mm*1.6mm) and low power consumption (10mA max with different kinds of sleep mode), which are all important for backpack for small animals like rat. C8051F007 is smaller and lighter than former processor (C8051F020) with two 12-bit digital to analog converters (DACs), which can output simultaneously and precisely.

The constant current source consists of two amplifies with one works as a voltage follower, which helps to give a feedback of load's voltage. Fig2 is the circuit diagram of constant current source. AD620, along with another op amp and one resistor makes a precision current source. The op amp buffers the reference terminal to maintain good CMR. The output voltage Vx of the AD620 appears across R1, which converts it to a current. This current less the input bias current of the op amp and then flows to the load. Therefore the amplifier used as a follower should have an input bias as low as possible. OPA2140 has a low input bias at 10pA max and its dual supply operation range is ±18V, rail to rail, which is enough to generate a pulse at ±10V. From the diagram we can get the value of the current by formula, shown in (1):

$$I_L = \frac{V_x}{R_1} = \frac{[V_{IN+} - V_{IN-}]G}{R_1} \qquad (1)$$

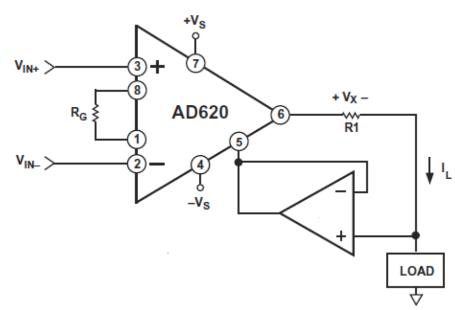


Fig.2. The circuit diagram of constant current source. AD620 is used as the main amplifier and OPA2140 is used as a feedback resistor.

DG409 is chosen as the analog switch for output connector. Its supply range is ±20V. DG409 has low on resistance (100Ω) and low power consumption (<11mW). The fast switching action (<250ns) is able to transmit waveform without distortion.

We choose a BTS2502C1H Bluetooth module of Jinoux Inc which weights 10g and sizes 36mm*22mm*2.5mm. The max baud rate is 1.3824 Mbps and can transfer data in a range of 100m. Considering the parameter used for stimulation is in small amount, we choose 9600 baud rate as the communication speed for consideration of power consumption.

B. Software

The control system on PC is written in Visual C++ 6.0 platform. The program in MCU is written in C. The protocol between PC and mainboard is by 14 parameters, consists of mode choice, pulse polar, pulse interval, pulse number, pulse duration and pulse amplitude (peak to peak voltage or current), as shown in Table Ⅰ. The software interface gives user permission to change all the parameters in a visualization interface.

Table Ⅰ. Protocol of Bluetooth module communication

Byte Index	Data
0,1	0xFF,0xFF
2	Mode(Current/Voltage)
3	Pulse polar
4,5	Pulse Interval
6,7	Pulse Number
8,9	Pulse Duration
10,11	Pulse amplitude
12,13	0xAA,0xAA

C. Animal experiment

The current stimulator are used to deliver brief trains of electrical stimulation through a pair of electrodes implanted in different brain regions (Left and Right somatosensory cortices (SI) whisker, Left and Right ventral tegmental area (VTA) and dlPAG) [14]. Four male Sprague-Dawley rats (marked F03, F06, E02 and V13) are used to test the voltage, current and behavior, shown in Fig.3. Among them, E02 has been at experiment for six months (over the best period of navigation); F03 and F06 have been used for about three months (during the best period of navigation); while V13 was just recovered from the surgery.

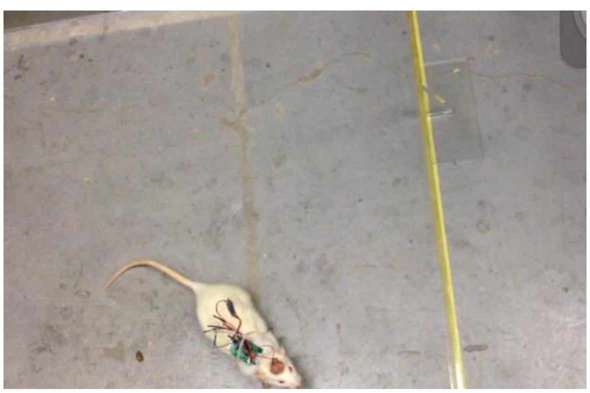
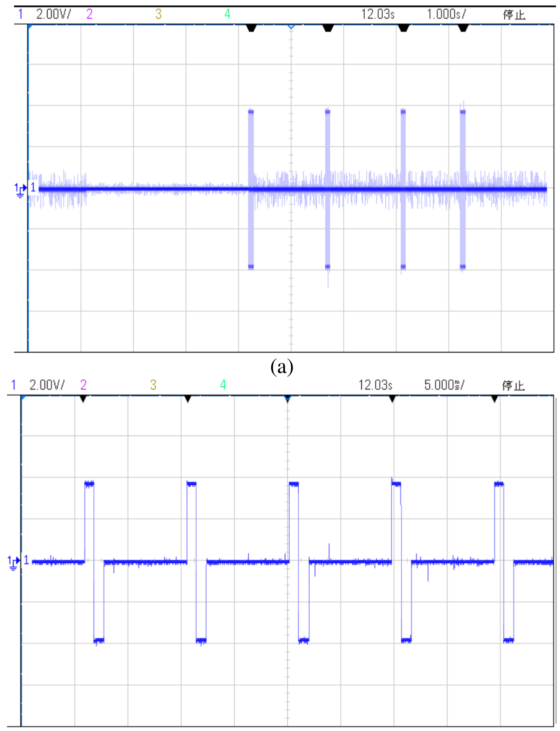


Fig. 3. The rat wan placed in a area of 2m*2m. The stimulation was sent during rat's movement to see its reaction.

RESULT

The feasibility of constant current was characterized by connecting the stimulator to a series of resistances, ranging from 1K to 15K. By changing the value of resistance we can test the consistency of the current. We choose 3K, 5K, 7K, and 9K as the typical value of resistor. An oscilloscope is used to record the waveform of the resistance. The stimulator gives a series of electrical pulse through DAC of C8051F007 processor, constant current source and analog switch. The waveform can be seen at Fig. 4. By confirming the parameter that communicate between Bluetooth modules in processor's debug mode we can make sure that all the parameters are transmitted precisely.



(a)

(b)

Fig.4 The waveform of stimulation shown in oscilloscope, two probes was put on the resistance which is linked in a channel of the stimulator. Although it is a voltage waveform, by dividing the resistance value we can get the current. (a) shows the pulse what stimulator sent when PC gives a commend. After enlarging (a) we got a series of pulse, shown in (b). We can see all the pulses in one series.

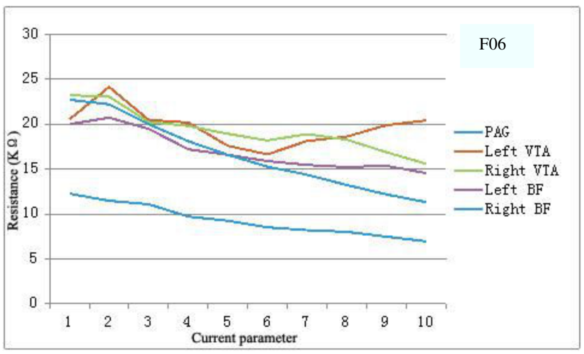
The power consumption of the whole system is 70mA for each stimulation. When turned into idle mode the current of the system will be much less. A Li - ion battery of 80 mA·h can support the stimulator to work for about 2 hours.

In experiments, we test the stimulator in different resistant load and find out the current that pass through the resistant stay constant and react quickly enough to the change of the load. This is because the feedback amplifier OPA2140 has a very high slew rate, which can help to feed back the change quickly. Table II shows the current value when load is changing. From the table we can see the current stays constant.

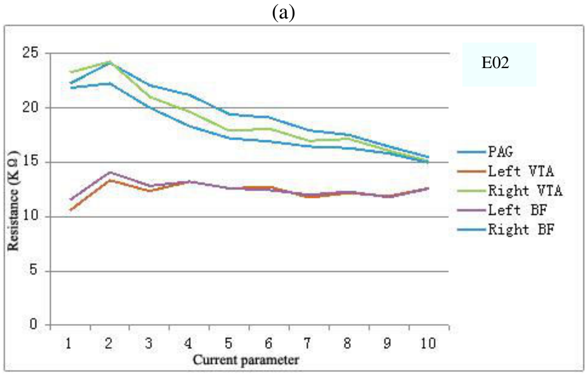
Table Ⅱ. Current value under different parameter and load

Resistance (KΩ) \ Parameter / Current (mA)	3	5	7	9
3	0.41	0.65	0.90	1.17
5	0.39	0.66	0.88	1.17
7	0.40	0.66	0.89	1.15
9	0.41	0.63	0.89	1.17

We then applied the current stimulator on our rat-robot. By varying the amplitude of the current (0 to 1.3mA) and recording the voltage between two electrodes of same pair, we can calculate the resistance of microelectrodes implanted in different area in rat's brain. The data is processed and the curve is shown in Fig.5. The resistance of the implanted electrodes will decrease with the increase of stimulation current in the diagram. This result could be explained by the fact that resistance of brain would change through different stimulation environment. In this way, current stimulator is better because it can gives a certain current stimulation regardless of the resistance of brain.



(a)



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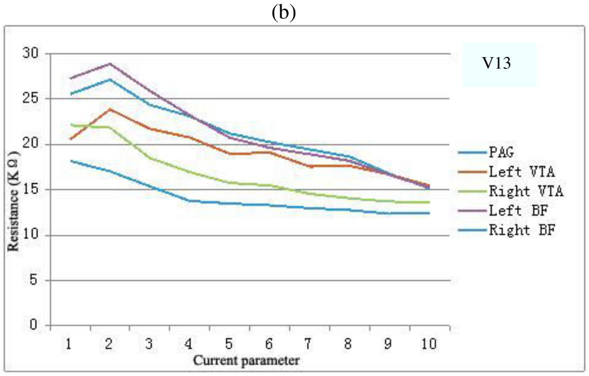

(c)

Fig. 5. These pictures show the resistances of rat's brain areas.

We finally test the effect of different amplitude current stimulation on animal behavior. We applied the current pulse on the dlPAG of free-moving rat (No.V03). The pulse duration is 1ms with 10ms interval. Each train contains 10 pulses. The current amplitude is ranging from 0 to 1.3 mA linearly. The rat behaved as normal under 0.1-0.25 mA current stimulation. When stimulated with current of 0.3-1.2 mA, the rat will stop moving and keep a "statue-like" state, which is a standard "freeze" reaction on dlPAG stimulation. With higher current (>1.2 mA), the rat will react more strongly, such as escaping or jumping. These results prove the constant current performance and demonstrated the possibility of using constant current stimulator on the navigation of our rat-robot.

CONCLUSION & DISCUSSION

A remote current stimulator for rat-robot is proposed in this paper. Using constant current source and components with lower power consumption and better performance, the stimulator can generate precise current pulse. We find out the nonlinearity of microelectrode resistance in rat's head under different current stimulation, which can be used to guide the design of parameters in the future.

This current stimulator can be further improved. For example, processors with lower power consumption can be sued, such as MSP430 to reduce the supply current. Furthermore, we can use 0603/0402 package to make the stimulator smaller and lighter. The experiments on rat are still ongoing to illustrate the change of the same microelectrode during the whole experimental period. Lastly and mostly, a better stimulator with better performance will be made to explore more detail in rat's brain in the future.

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