Wireless Neural Stimulator with Adjustable Electrical Quantity

Young-Seok Choi

***Abstract*—**The neural stimulation has been gaining much interest in neuromodulation research and clinical trials. For efficiency, there is a need for variable electrical stimulation such as current and voltage stimuli as well as wireless framework. In this regard, we develop the wireless neural stimulator capable of voltage and current stimuli. The system consists of ZigBee which is a wireless communication module and stimulus generator. The stimulus generator with 8-bits resolution enable both mono-polar and bi-polar waveform in voltage (-3.3~3.3V) and current (-330~330μA) stimulus mode which is controllable. The experimental results suggest that the proposed neural stimulator can play a role as an effective approach for neuromodulation.

***Keywords*—**Neural stimulator, current stimulation, voltage stimulation, neuromodulation.

I. Introduction

OVER recent decades, a large number of neural stimulation based on electronics has been developed for clinical treatment of various neuronal disorder such as epilepsy, stroke, pain, essential tremor, blindness [1]-[3] and spinal cord injury, bladder control, drop foot and grasping [4], [5] to restore some of the lost motor function.

The electrical stimulation approach using current and voltage pulses has been reported in literature, the applied stimulus amplitudes are spread over a wide range. Stimulation with brief voltage pulses (100 s) required amplitudes of 0.6–2.5 V, which could also result in current peaks of several microamperes [6]-[8]. However, the current and voltage stimuli were prefixed as monophasic or biphasic pattern, limiting their usage.

Here, we present a generalized wireless neural stimulator which yield both voltage and current stimuli. By controlling the type and parameters of the stimulus, the proposed neural stimulator would widen the application. In addition, the use of wireless stimulus transceiver enables stable experiment for freely moving animals

II. Hardware Configuration

The proposed stimulator is shown in Fig. 1 and mainly consists of the wireless transceiver module and the stimulus generator module. As the wireless transceiver, a commercial Zigbee module (ZBS-100, Roboblock) is used. The ZigBee technology is well-known a low data rate, two-way standard for home automation and data networks. The ZigBee standard uses small very low-power devices to connect together to form a wireless control web [9]. The standard supports 2.4GHz unlicensed radio bands.

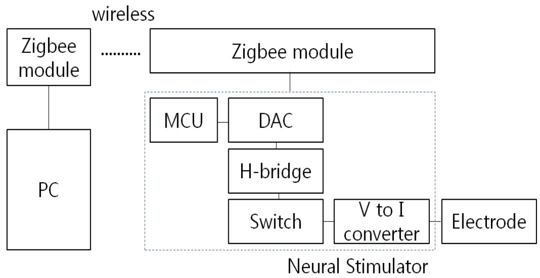


Fig. 1 System configuration block

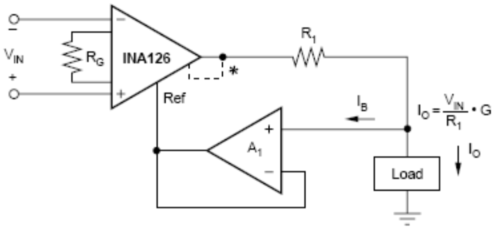


Fig. 2 Voltage to current converter circuit

TABLE I
STIMULATOR SPECIFICATION

Channel/Pulse Width	4	10μs~
Voltage range/ Resolution	-3.3~3.3V	8 bit
Current range/ Resolution	-330μA~330μA	8 bit
Battery/ Rate	Li-Po 120mAh	~1kHz
Stimulation pulse	Mono, Bi-phasic voltage and current pulse	

The neural stimulator module includes MCU (Atmega128l, AVR), DAC (DAC5574, TI), H-bridge circuit and voltage-current converter circuit shown in Fig. 1. H-bridge is used to implement the biphasic stimulus pulse. Voltage and current stimuli via a switch connected to the MCU can be selected by user.

The voltage stimulus is obtained from the output of H-bridge circuit, and the current stimulus is taken by output of the voltage to current converter circuit. The circuit is shown in Fig. 2. If the current stimulation is selected, the switch is used. The current stimulus range is shown in typical performance the current range is limited on the resistor, R_1, and gain.

The output constant current can be expressed as:

$$I_o = \frac{V_{in}}{R_1} \times G \tag{1}$$

Y.-S. Choi is with the Department of Electronic Engineering, Gangneung-Wonju National University, 7 Jukheon-gil, Gangneung, 210-702 Republic of Korea (phone: +82-33-640-2429; fax: +82-33-646-0740; e-mail:yschoi@gwnu.ac.kr).

The current is constant regardless of load which is connected to the electrodes.

Gain is set by connecting an external resistor, R_G, as follows:

$$\text{Gain}=5+\frac{80k\Omega}{RG} \tag{2}$$

The stimulator of specification is shown in Table I. The output of voltage range is -3.3V~3.3V, having 8 bit resolution.

III. Software Configuration

For a remote control of stimulation, user can select some stimulation waveform parameters through the custom-made GUI software on PC. The parameters are sent to the stimulation generator through the ZigBee transceiver connected to RS232 port.

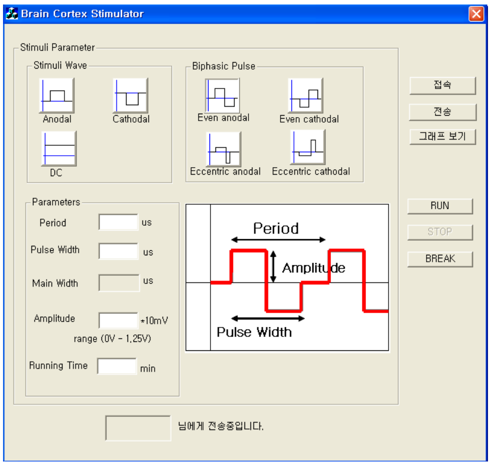


Fig. 3 PC interface GUI for stimulation controller

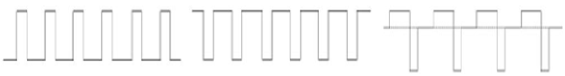


Fig. 4 Stimulation waveform type (positive, negative, and biphasic pulses)

We designed and implemented the user interface software for wirelessly communicating with the stimulator. A window-based stimulator interface was depicted in Fig. 3. It provides the selection of the stimulation parameters such as period, pulse width, amplitude and stimulation running time. The available three types of stimulus waveform are two monophasic pulses (positive and negative, respectively) and biphasic shown in Fig. 4. The period and the pulse width are in range of several micro seconds. And the amplitude has values of several milli-voltages. The stimulation running time is adjustable within several minutes.

The stimulation parameters obtained from PC software are sorted in data packet shown in Fig. 5 prior to sending. The data packet consists of the data and the address of the data so that the received data can be easily organized in proper control registers. Then the microcontroller generates the stimulus waveform according to the selected parameters.

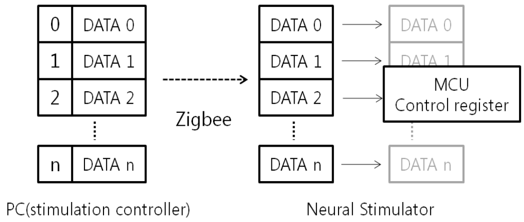


Fig. 5 Data packet structure

IV. Experiment

It is known that the whisker area of somatosensory cortex (known as barrel cortex) is arranged as a topographic map of the whiskers [10]. It means that sensory informative signal arisen due to one whisker is delivered through a restricted population of neurons, being measured by an electrode at different area in sensory pathway. Among a rat brain, we focus on whisker sensory area including SI (Primary somatosensory cortex) and MFB (Median Forebrain Bundle).

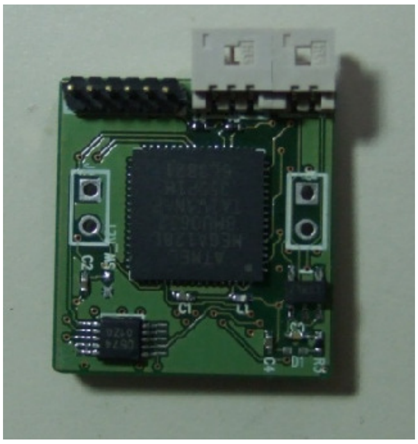
The MFB is related with the reward system, involved in the integration of reward and pleasure. It has been believed that an electrical stimulation on MFB cause sensations of pleasure.

Rat whiskers move actively in one dimension, rotating at their base in a plane roughly parallel to the ground. When the whiskers hit an object, they can be deflected backwards, upwards or downwards by contact with the object. The mechanical bending of the whisker activates many thousands of sensory receptors located in the follicle at the whisker base. The receptors, in turn, send neural signals to the brain, where a three-dimensional image is presumably generated.

Our experiment is grounded on that rat exploratory whisking is modulated by environmental contact [11]. Normal rats by stimulating SI are able to control the direction. The five normal Sprague Dawley rats with 7 week (270~300 g) were used in the experiment.

We carried out the direction control experiments of rats by using the proposed wireless stimulator. The wireless neural stimulator used experiment is shown in Fig. 5. Its size is 10 x11mm.

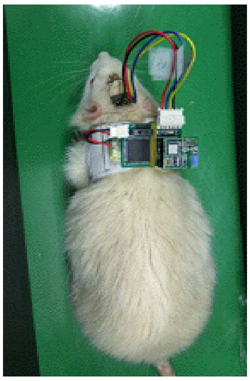
(a)



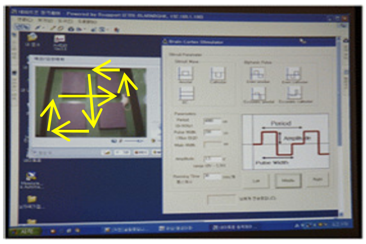
(b)

Fig. 6 The wireless neural stimulator (a) upside view (b) downside view

The system consists of three separated components: a transmitter (using ZigBee telecommunication) base station that is controlled by a PC operator, a 3 channels (right, left, and straight) remote-controlled stimulator backed by rat, and a computer cam based rat motion analysis system as shown in Fig. 6 (b). The electrodes located in the normal rat's whiskers and the MFB was stimulated with biphasic voltage pulse.



(a)



(b)

Fig. 7 (a) Rat equipped with the voltage stimulator (b) The experimental setup with online monitoring

TABLE II
STIMULATION PARAMETERS

Train duration (ms)	200~400
Pulse amplitude (V)	±1.5~2.5
Pulse interval (ms)	4
Period (Hz)	250
Stimulus intensity (mA)	0.15~0.25
Number of pulse	5~10
Pulse width (ms)	0.1 (positive) + 0.1 (negarive)

The stimulation parameters used are shown in Table II. The range of pulse amplitude is ±1.5~2.5V. The number of pulse is 5~10. Stimulation threshold for each rat was defined as the experimental values. In each direction use the same stimulation. The rat's position was monitored and confirmed whether or not the right direction. We tested the control ability of rats to go through a maze.

V. CONCLUSION

For a generalized neural stimulator, we present a generalized voltage-current selectable stimulator. Various stimulus parameters can be selected in accordance with the target experiment. In addition, user can select voltage or current stimulation mode.

Preliminary results suggest that the proposed wireless neural stimulator can serve as an effective neuromodulation tool for freely moving animals in diverse experiments.

In future experiments, we would integrate sufficiently small and low-power battery into stimulator block and develop the overall experimental closed loop system.

REFERENCE

[1] S.C. DeMarco, W. Liu, P.R. Singh, G. Lazzi, M.S. Humayun, J.D.Weiland, "An arbitrary waveform stimulus circuit for visual prosthesis using a low-area multibias DAC", *IEEE J. Solid-State Circuits* 38 (10) 1679–1690, 2003.

[2] K.D. Wise, D.J. Anderson, J.F. Hetke, D.R. Kipke, K. Najafi, "Wireless implantable microsystems: high-density electronic interfaces to the nervous system", *Proc. IEEE* 92 (1) 76–97, 2004.

[3] M. Ghovanloo, K. Najafi, "A modular 32-site wireless neural stimulation microsystem", *IEEE J. Solid-State Circuits* 39 (12) ,2004.

[4] M. Sawan, Y. Hu, J. Coulombe, "Wireless smart implants dedicated tomultichannel monitoring and microstimulation", *IEEE Circuits Syst.Mag*. 21–39, 2005.

[5] S. Boyer, M. Sawan, M. Abdel-Gawad, S. Robin, M.M. Alhilali, "Implantable selective stimulator to improve bladder voiding: design and chronic experiment in dogs", *IEEE Trans. Rehab. Eng.* 8 (4) 789–797, 2000.

[6] Y. Jimbo, T. Tateno, and H. P. Robinson, "Simultaneous induction of pathway-specific potentiation and depression in networks of cortical neurons," *Biophys. J.*, vol. 76, pp. 670–678, 1999.

[7] T. Tateno and Y. Jimbo, "Activity-dependent enhancement in the reliability of correlated spike timings in cultured cortical neurons," *Biol. Cybern.*, vol. 80, pp. 45–55, 1999.

[8] Y. Jimbo, H. P. Robinson, and A. Kawana, "Strengthening of synchronized activity by tetanic stimulation in cortical cultures: Application of planar electrode arrays," *IEEE Trans. Biomed. Eng.*, vol. 45, pp. 1297–1304, Nov. 1998.

[9] Jui-Yu Cheng and Min-Hsiung Hung , Jen-Wei Chang, "A ZigBee-Based Power Monitoring System with Direct Load Control Capabilities," in *Proceedings of the 2007 IEEE International Conference on Networking, Sensing and Control*, London, UK, 15-17 April 2007.

[10] Woolsey ta,Vander Loos ," The structural organization of layer IV in the somatosensory region (SI) of mouse cerebral cortex: the description of a cortical field composed of discrete cytoarchitectonic units." *Brain*

Research 17, 205-242. 1970.
[11] Ben Mitchinson, Chris J. Martin, Robyn A. Grant and Tony J. Prescott, "Feedback control in active sensing: rat exploratory whisking is modulated by environmental contact", in 2007 *Proc. R. Soc. B* 274, 1035–1041.