Journal of Neuroscience Methods 174 (2008) 186–193

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

A portable telemetry system for brain stimulation and neuronal activity recording in freely behaving small animals

Xuesong Ye[a,b,c], Peng Wang[a,b,c], Jun Liu[a,b,c], Shaomin Zhang[a,b,c], Jun Jiang[a,d], Qingbo Wang[a,b,c], Weidong Chen[a,d], Xiaoxiang Zheng[a,b,c,*]

[a] *Qiushi Academy for Advanced Studies, Zhejiang University, Hangzhou 310027, PR China*
[b] *Key Laboratory of BME of the Ministry of Education, Hangzhou, Zhejiang, PR China*
[c] *Department of Biomedical Engineering, Zhejiang University, Hangzhou 310027, PR China*
[d] *College of Computer Science and Technology, Zhejiang University, Hangzhou 310027, PR China*

ARTICLE INFO

Article history:
Received 24 December 2007
Received in revised form 30 June 2008
Accepted 2 July 2008

Keywords:
Neuronal signal telemetry
Neuronal activity recording
Electrical stimulation
Portable system

ABSTRACT

A portable multi-channel telemetry system which can be used for brain stimulation and neuronal activity recording in freely behaving small animals is described here. This system consists of three major components of headstage, backpack and portable Personal Digital Assistant (PDA). The headstage contains high precision instrument amplifiers with high input impedance. The backpack is comprised of two parts: (1) a main board (size: 36 mm × 22 mm × 3.5 mm and weight: 40 g with batteries, 20 g without), with current/voltage stimulator and special circuit suitable for neuronal activity recording and (2) and a bluetooth transceiver, with a high data transmission rate up to 70 kb/s, suitable for downloading stimulation commands and uploading acquired data. We recorded neuronal activities of the primary motor area of a freely behaving rat with 12-bit resolution at 12 k samples/s. The recorded data and analysis results showed that the system was successful by comparing with the commercial equipment Cerebus™ 128-Channel Data Acquisition System (Cyberkinetics Inc.). Using the PDA, we can control stimulation and recording. It provides a flexible method to do some research work in the circumstances where other approaches would be difficult or impossible.

1. Introduction

Both electrical stimulation (Ranck, 1975; Tehovnik, 1996) and neuronal activity recording (Salinas and Sejnowski, 2001) are fundamental tools in neurophysiology. Because cables limit the movement freedom of subject and some experiments can only be done in a simplest environment, for the researcher, telemetry is a useful technology to be adopted in some special cases.

The telemetry systems for electrical stimulation (Holzer and Shimoyama, 1997; Xu et al., 2004; Wang et al., 2006; Song et al., 2006; Feng et al., 2007) or neuronal activity recording (Grohrock et al., 1997; Hawley et al., 2002; Obeid et al., 2004; Chien and Jaw, 2005; Schregardus et al., 2006; Jürgens and Hage, 2006; Vyssotski et al., 2006; Ativanichayaphong et al., 2008) have been reported in recent years. In one demonstrator, electrical stimulation of the somatosensory cortex (SI) and medial forebrain bundle (MFB) was used as cues and rewards to condition distant rats to execute controlled turns remotely (Talwar et al., 2002). Xu et al. (2004) designed a typical stimulation system which could be used for controlling freely roaming animals. Hawley et al. (2002) developed a one-channel telemetry system to record the location-specific activities of hippocampal cells from untethered rats. A multi-channel telemetry system (Obeid et al., 2004) was successfully used to record neural activities from awake, chronically implanted macaque and owl monkeys. Schregardus et al. (2006) designed a lightweight telemetry system for recording neuronal activities in zebra finches, and multi-channel recording telemetry systems have been also described by other authors (Nieder, 2000; Jürgens and Hage, 2006). However, these systems are incompetent to carry on a task of both electrical stimulation and recording in freely behaving small animals, while the combining of stimulation and recording to bring a feedback of control and measurement may be highly useful in studying the neural correlates of stimulation and responses while directing freely moving animals (Xu et al., 2004).

It would be desirable if the bidirectional communication system could be developed on the basis of the unidirectional one. However, with the limitations of transmission speed, power consumption, bandwidth, distance, signal-to-noise ratio, small size,

* Corresponding author at: Zhejiang University, Qiushi Academy for Advanced Studies, Room 505, Zhouyiqing Technology Building, Zheda Road 38#, Hangzhou 310027, Zhejiang Province, PR China. Tel.: +86 571 87953860; fax: +86 571 87951676.
E-mail address: zhengxx@mail.zju.edu.cn (X. Zheng).

0165-0270/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.jneumeth.2008.07.002

etc., it is not easy to develop a telemetry system for small animals. The transmission speed of present stimulation systems based on the normal serial port of PC is low (normally less than about 12 kb/s at 128,000 baud). This is suitable for transferring one-channel neuronal signals, but not multi-channel signals (Jaw, 2001). As to the recording system, an analog communication mode is widely used for transferring the electrical physiology signals from the small animal bodies to the recording devices. The analog mode has the advantages of high-speed communication, small size, light weight and low power consumption when transmitting one-channel signals (Hawley et al., 2002; Lin et al., 2008). In these systems, neither Analog-to-Digital Converter (ADC) nor microprocessor is necessary for converting analog signals into digital signals to the transmitter. But adding a stimulation function to the system using the analog communication mode requires some complex logic circuits to translate the different commands of the controller. Moreover, multi-channel signal transmission would make circuits more complex. With respect to the quality of transmitted signals, the analog system is susceptible to the transmission channel noise, which may affect neuronal spike (i.e., neuronal action potentials) sorting (Kim and Kim, 2000). Last, we should mention that most of these telemetry systems consist of a wearable telemetry unit which communicates with a stationary host computer or laptop PC, so it is not easy for the whole system to move.

Described here is a new telemetry system for both brain stimulation and neuronal activity recording in freely behaving small animals. The digital communication mode based on bluetooth to the Universal Serial Bus (USB) interface of the PDA is used as a uniform mode both for transmission and receival. The portable PDA can control the backpack to produce four-channel stimulus and acquire two-channel neuronal signals in real time. It is a real mobile system that can work in circumstances where other approaches would be difficult or impossible.

2. Methods

2.1. Overview

The system we have developed can deliver brief trains of electrical stimulation to four different brain locations, each implanted with a pair of electrodes. It can also acquire neuronal action potentials (APs) and local field potentials (LFPs) from two different places of the brain simultaneously. The system consists of three main components: headstage, portable PDA and backpack (Fig. 1a is a schematic diagram, Fig. 1b is an actual photo of this system and Fig. 1c is an actual photo of the backpack.). Two bluetooth modules are used for wireless communication. On the PDA side, the bluetooth transceiver is connected to the portable PDA through its USB port by a USB to UART module. The USB to UART module can enhance the transmission rate between PDA and bluetooth module. On the backpack side, the microprocessor has a high-speed UART port connecting the bluetooth transceiver directly.

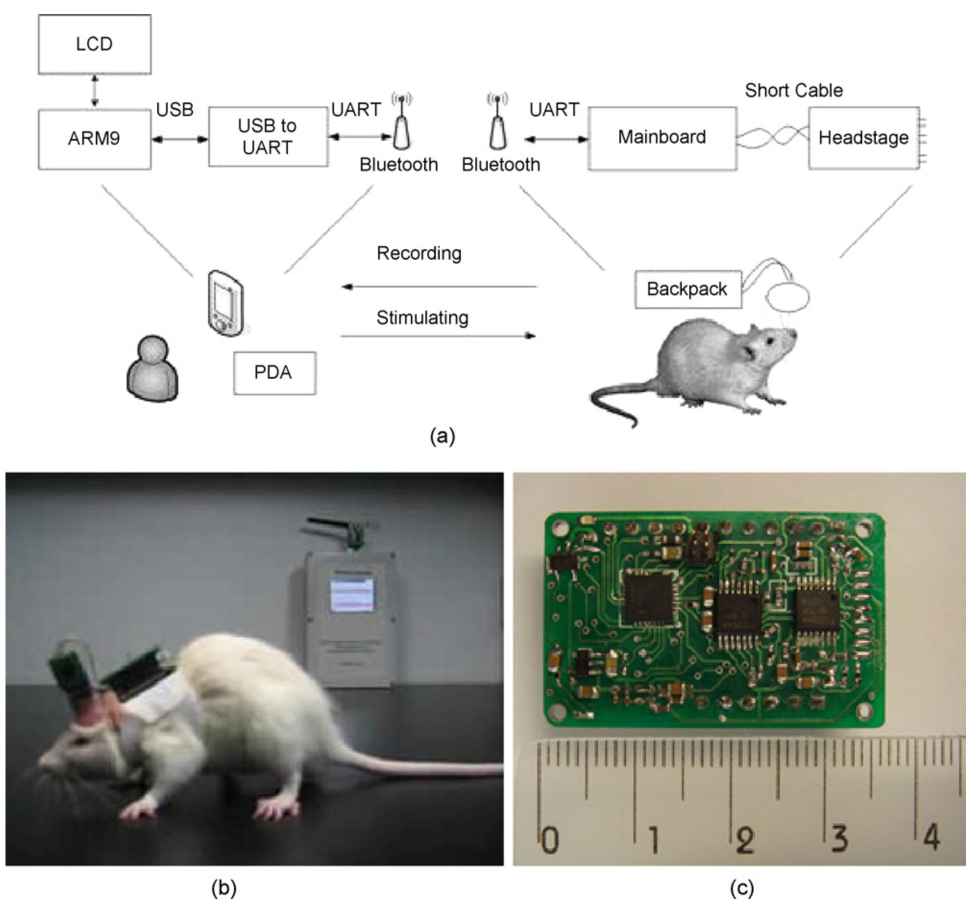

Fig. 1. (a) Overview of the multi-channel stimulation and recording system. The system consists of three major components of headstage, backpack and portable Personal Digital Assistant (PDA). The headstage is placed on the rat head directly. The backpack consists of headstage and main board. The C8051F411 on the main board is used as the microcontroller of the backpack. The PDA is used to control the backpack through bluetooth wireless link, which consists of ARM9 processor, LCD and touch screen module, and USB to UART convert circuits. (b) An actual photo of this system. The rat implanted with a recording electrode array wears the headstage and backpack and its neuronal signals are acquired by the prototype of the PDA. (c) An actual photo of the backpack.