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A wearable wireless system for olfactory neural recording in freely moving rats based on Wi-Fi technology

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ABSTRACT

A battery-operated wearable wireless olfactory neural recording system (WONRS) based on Wi-Fi technology is presented and characterized for recording individual olfactory neural activities from freely moving rats. The WONRS that constructed of an amplifier headstage, backpack board and user interface software is capable of transmitting up to 54 M bits per second (Mbps) of raw streaming data using IEEE 802.11 g protocol, and can examine and store 8 channels of captured olfactory neuronal firing data synchronously. Since the packets are transmitted over the wireless local area network (WLAN), the WONRS provides a capability of being operated over a very large distance, which enables experimenters to be able to operate the device within almost any laboratory or open field context. A major advantage of the WONRS is the high bandwidth and long transmission range afforded by Wi-Fi technology. Using the WONRS, continuous olfactory neural recordings from an awake and behaving rat were performed. Also, WONRS measured the responses of M/T cells under carvone as odorant stimulation over multiple days. This biosensing system could continuously record the response signal of olfactory neuron and, furthermore, had good stability and long working life.

1. Introduction

Olfactory neuronal activity is recorded by neuroscientists to examine olfactory neural firing correlates from behaving rats and decode odorant information. In those experiments, clumsy instruments and tethered wires greatly limit the behavior of live rats and testing situations. Therefore, a lightweight and wearable wireless neural recording system (WONRS) capable of transmitting multi-channel signals in real-time within more complex recording environments is tremendously needed [1].

Works about WONRS were performed to accommodate the experimentalist and engineering, and are visible on the very different engineering solutions proposed and implemented successfully by several laboratories and companies [2–5]. Both digital transmission such as FSK, QFSK and Bluetooth, and analog transmission such as FM, were used [6–10]. However, many of the systems with wireless links are not fully implantable and require large backpacks [11–13], or do not permit action potential recordings and cannot afford high bandwidth transmissions [14].

Our goal is to replace the multi-conductor cable with a high bandwidth wireless interface to allow the subject more mobility and more natural response to a given experiment. In this paper, we present a wearable 8-channel WONRS that utilizes Wi-Fi technology to transmit olfactory neural signals in awake and behaving animals. The major hardware features of this modular system include a planar array with 8 microelectrodes and supporting hardware incorporating AC-coupled buffer and filter stages and embedded Wi-Fi module. The WONRS has a pass-band extending from 0.5 Hz to 4 kHz and can capture neural signals in the range of 50 μV–1 mV. The WONRS record both local field potentials (LFPs) and neuronal spike activity and transmit data packets using IEEE 802.11 g protocol. The WONRS provides a capability of remote operation and can be used for almost any experimental environment. To demonstrate the utility of this system, continuous neural recordings from a conscious rat's olfactory bulb have been performed over a very large distance separations from the monitor station. To examine the stability of developed biosensing system for continuous recording, WONRS was employed to detect and analyze the responses of M/T cells from the same recording channel over multiple days. Meanwhile to compare with that without odorant

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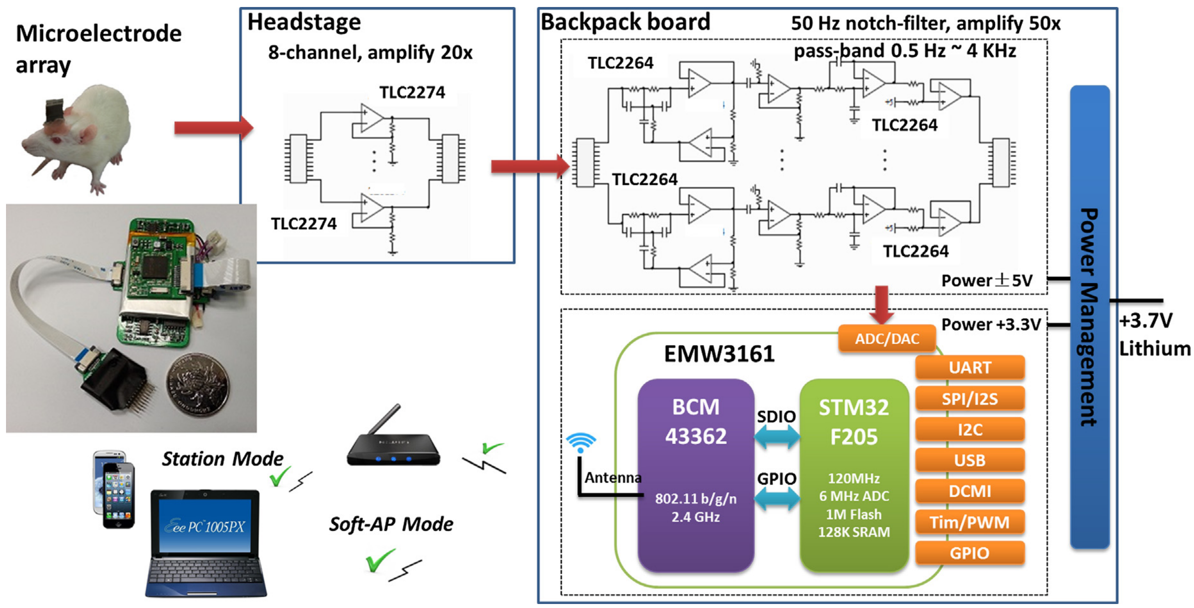

Fig. 1. System architecture of the wireless olfactory neural recording system (WONRS). The picture at middle left shows the WONRS prototype constructed of a backpack board and an 8-channel amplifier headstage. The diagrams illustrate each stage of processing and transmission. Microvolt-level neural signals from the microelectrode which are packaged in a 10-pin single inline package (SIP) are amplified 20× by the headstage. The amplified signals are then band-pass filtered from 0.5 Hz to 4 kHz, and amplified 50× before input to the STM32F205 microcontroller embedded in the EMW3161 Wi-Fi module. Pre-processed neural signals are analog-to-digital (A/D) converted by high speed 12-bit ADCs integrated in the STM32F205 and transmitted to the host computers or mobile phones via the wireless local area network (WLAN). User software designed using Labview programming language records and handles the captured neural data for real time display. A 3.7 V lithium battery is used to power the WONRS.

stimulation, WONRS measured the response signal which was generated from the stimulation of odorant at high concentration.

2. Materials and methods

Fig. 1 depicts the block diagram of proposed olfactory neural recording system. The WONRS prototype consists of two major parts: (A) a hardware interface including a headstage and backpack printed circuit board (PCB), and (B) a user interface containing a HTTP2 server and user software. The headstage that directly connected to the implanted electrode array amplifies the neural signals first. And then the signals are filtered and amplified by the signal conditioning circuit in the backpack PCB. After digitizing with 12-bit analog-to-digital (A/D) converter, the olfactory neural signals are transmitted to host computers or mobile phones over the WLAN. A user software is programmed with LabView 2011 to handle the captured data. A HTTP2 server is also available for experimenters to view the status information of the device and configure the WLAN.

2.1. Hardware interface

The hardware interface consists of three main parts: power management, neuronal signal conditioning and embedded Wi-Fi module. The power was provided by the voltage converted with DC/DC converters (TPS61200, TPS63700, TPS63031, and Texas Instruments) from single lithium battery (+3.7 VDC). Olfactory neural signals were detected by the micro-wire in microelectrode array, then coupled directly to the headstage amplifiers (TLC2274, Texas Instruments) for amplification of 20 times. After that, the signals were coupled to a 50 Hz notch filter and the second stage of amplification (TLC2264, Texas Instruments) for noise removal and 50-fold amplification. The clean signals were obtained after several filters and transferred to the embedded Wi-Fi module (EMW3161, Mxchip). Finally, the embedded Wi-Fi module exchanged with user interface for the neuronal signal data.

2.2. User interface

As show in Fig. 2, the user interface consists of two main parts: (A) a user software that handles the data received from the embedded Wi-Fi module and control the STM32 applications, and (B) a HTTP2 server for network configuration and firmware updating.

3. Results and discussion

In order to demonstrate the efficacy of the WONRS, the system was used to collect data from micro-wire electrodes implanted in the olfactory bulb (OB) of an awake and behaving rat.

3.1. Microelectrodes and surgical procedures

In this study, olfactory neural recordings were obtained using a 8-channel home-made micro-wire (65 μm in diameter, AM system, WA; #762000) array electrodes [15] packaged in a 10-pin SIP. The microelectrode contains two parallel rows of 4 micro-wires each. The distance between micro-wires in a row varied from 100 to 200 μm, and the distance between two rows varied from 200 to 300 μm (Fig. 3A). We chronically implanted the microelectrode in the dorsal aspect of rats' OB; electrophysiological recording was acquired by attaching the connector of microelectrode to pre-amplifier with headstage cable connected to the WONRS.

During electrode implantation process, adult male Sprague-Dawley rat (230–270 g) was anesthetized with an intraperitoneal injection of chloral hydrate (4 mL/kg). The rat was held in a standard stereotaxic apparatus, and a craniotomy was performed to expose the dorsal aspect of OB. After craniotomy had been done, microelectrode was touched down the surface of dorsal OB using micromanipulator (Fig. 3B). Surgical and experimental