International Journal of Scientific Research in Science, Engineering and Technology
Print ISSN: 2395-1990 | Online ISSN : 2394-4099 (www.ijsrset.com)
doi : https://doi.org/10.32628/IJSRSET

Wearable and Wireless Brain Sensors

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Article Info
Volume 8, Issue 6
Page Number : 285-288
Publication Issue :
November-December-2021
Article History
Accepted : 15 Dec 2021
Published: 30 Dec 2021

ABSTRACT

Electroencephalogram (EEG) is a powerful non-invasive tool widely used for both medical diagnosis and neurobiological research as it provides high temporal resolution in milliseconds.

It involves sensors light enough to allow near-complete freedom of movement of the head and body, making EEG the clear choice for brain imaging of humans performing normal tasks in real-world environments.

Keywords : SENSOR, WIRELESS, EEG

I. INTRODUCTION

Need for the intervention:

- The lack of portable and user-acceptable (e.g., comfortably wearable) sensors and miniaturized supporting hardware/software to continuously acquire and process EEG has long thwarted the applications of EEG monitoring in the workplace.

Specialty in technical advancement:

- A prototype fourchannel mobile and wireless EEG system incorporating a miniature data acquisition (DAQ) circuitry and dry Micro-Electro-Mechanical System (MEMS) electrodes with 400 ganged contacts for acquiring signals from non-hairy sites without use of gel or skin preparation.

- This study extends our previous work, NCTU BCI-cap [2-4], to a smaller, lighter, wearable & wireless brain-computer interface (BCI), NCTU BCI-headband.

Features of NCTU BCI –Headband

(1) Disposable dry MEMS electrodes;
(2) An 8-channel DAQ unit;
(3) Wireless telemetry and
(4) Real-time digital signal processing (DSP) implemented on a commercially available cell phone or a digital signal processing module.

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Application:

To EEG monitoring in operational environments was demonstrated by a sample study: cognitive-state monitoring and management of participants performing normal tasks in real-world environments.

Integration of sensors

- Dry MEMS Electrodes and Electrode Holders
- Data Acquisition Unit
- Wireless Transmission Unit
- Real-Time Digital Signal Processing Unit
- Data-Logging and Digital Signal Processing on a Cell Phone

a) **Dry MEMS Electrodes and Electrodes Holders**

The use of MEMS technology to build a silicon-based spiked electrode array or so-called dry electrode, to enable EEG, EOG, ECG, and EMG monitoring without conductive paste or scalp preparation [2-4]. However, the connectors between the dry sensors and DAQ board were not very robust in the BCI-cap. This study incorporated snap-on electrode holders to house dry electrodes or commercially available EEG sensors.

b) Data Acquisition Unit

The data acquisition unit integrated an analog preamplifier, a filter, and an analog-todigital converter (ADC) into a small, lightweight, battery-powered DAQ. EEG signals are sampled at 512Hz with 12-bit precision, amplified by 6000 times, and band-pass filtered between 1 and 50 Hz. Fig. 2A shows the block diagram of the DAQ unit. Fig. 2B shows the DAQ unit for each electrode (20mm x 18mm PCB ‘node’). To reduce the number of wires for high-density recordings, the power, clocks, and measured signals are daisy-chained from one node to another with bit-serial output. That is, adjacent nodes (electrodes) are connected together to (1) share the power, reference voltage, and ADC clocks, and (2) daisy chain the digital outputs

c) Wireless Transmission Unit

The wireless-transmission unit consisted of a wireless module and a micro-controller. It used a Bluetooth module to send the acquired EEG signals to a custom real-time DSP unit described below or a Bluetooth-enable cell phone which was used as a realtime signal-processing unit. The dimension of the wireless transmission circuit was 40 x 25 mm2 . Figure 2D shows a picture of the integrated 4-channel wireless EEG system.

d) Data logging and Digital Signal Processing on a Cell Phone

To be practical used in operational environments, the signal processing unit must be light-weight, portable, low-power, and have on-line data receiving and real-time signal processing function. Therefore, this study designed and developed a real-time digital signal processing unit which used a Bluetooth module to receive the acquired EEG signals from the NCTU BCI-headband and process the EEG signals via its core processor in near real-time. The core processor is the Blackfin processor (Analog Device Incorporation, ADSP-BF533) which provided a high performance, powerefficient processor choice for demanding signal processing applications. The dimension of the miniature DSP unit is about 65 x 45 mm2 (as shown in Figure 4). The maximum high processing performance of the BF533 core processor can reach 600MHz. Furthermore, the following peripheral modules were also incorporated in the unit. • SD RAM and FLASH memory • RS-232 serial interface • Six keypads and a LCD panel (240 by 320 pixels) • JTAG interface for debug and FLASH programming

Testing of NCTU BCI-Headband

1. **Comparison between the NCTU BCI-Cap and BCI-Headband**

Lin et al. [2] reported a 4-channel BCI-cap which measured EEG and transmitted it to a commercially available DSP kit by Texas Instruments. This study extended the EEG recording system into a truly mobile brain-computer interface which acquired and processed EEG signals in near real-time. Table 1 compares the specifications and features of the BCI-cap and those of the BCI-headband. It is evident that, compared to BCI-cap, BCI-headband is lighter, smaller, more power-efficient and accommodates more channels with higher sampling rate and digitization precision.

2. **Real-Time Alertness Monitoring Using NCTU BCI-Headband and a Cell Phone**

Lin et al. recently demonstrated the feasibility of using dry MEMS EEG electrodes, supporting hardware and commercially available TI DSP kit to continuously and accurately estimate the driving performance (putative drowsiness level) based on EEG data from four frontal non-hairy positions in a realistic VR-based dynamic driving simulator. This study implemented the cognitive-state monitoring algorithm on a Bluetooth-enable cell phone that received EEG signals and processed them with the on-board processor. The cell phone delivered arousing feedback when the participants were drowsy. Figure 5A shows the flowchart of the signal processing implemented on the cell phone. Figure 5B shows the evident alpha activities when the subject was drowsy.

Conclusions

- This study demonstrated a truly portable, lightweight, and readily wearable braincomputer interface that featured dry MEMS electrodes and a miniaturized DAQ, wireless telemetry and online signal processing. The main goal of the design and development of wearable and wireless BCI is to maximize their wearability, unconstrained mobility, usability and reliability in operational environments.
- In this study, the signal-processing module and the Bluetooth-enable cell phone were programmed to assess fluctuations in individuals' alertness and capacity for cognitive performance based on the EEG signals. The BCI delivered arousing feedback to the driver to maintain optimal performance. The cell phone and DSP unit, however, can be programmed for many other brain-system interface applications.

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Cite this article as :

Nandhini S, "Wearable And Wireless Brain Sensors", International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Online ISSN : 2394-4099, Print ISSN : 2395-1990, Volume 8 Issue 6, pp. 285-288, November-December 2021.
Journal URL : https://ijsrset.com/IJSRSET218650