Portable qEEG and HD-tCS Device for Point-of-Injury Traumatic Brain Injury Diagnostics

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Abstract. Mild Traumatic Brain Injury (mTBI) can cause prolonged or permanent injuries if left undetected and ignored. It is therefore of great interest to lower the threshold for diagnosis of individuals with mTBI injury. We report on the development of a prototype of a portable quantified EEG system intended for in-the-field mTBI diagnostics. The 32-electrode system is fully battery driven, is interfaced with a control unit being part of a telemedicine care system. All electrodes are individually configurable sot that they can be used for wet or dry qEEG electrodes. All electrodes can also be individually configured to allow Trans-Cranial Current Stimulation (tCS) sessions in DC, AC or other current supply modalities. The system has been functionality tested in end-to-end configurations where all control and measurement signals are forwarded between the head device on one side and the user interface and telemedicine system on the other. Tests confirm that the device can acquire and forward EEG data from 32 channels in parallel at target sensitivities up to 1 kHZ sampling frequencies. Tests further confirm that all electrodes can be individually configured for DC or any alternating current waveform up to 1 kHz. Additional device clinical evaluation is planned.

Keywords. Traumatic Brain Injury (TBI); Electroencephalography (EEG); Diagnosis; Portable Medical System; Trans-Cranial Current Stimulation (tCS)

1. Introduction

Traumatic Brain Injury (TBI) can be defined as brain damage caused by an external force acting to the head, and resulting in a temporary or permanent impairment of brain function. TBI is a major health concern with overall incidence of hospitalized and fatal TBI ranging from 100 to 300 per 100,000 inhabitants per year [1], [2], [3]. Mild TBI (mTBI), e.g., concussion, represents 70-90% of all known TBI cases, but these are often not properly diagnosed. It is desirable to diagnose TBI at an early stage since undetected incidents can lead to delayed convalescence and risk of prolonged or permanent injuries, but current diagnostic and treatment opportunities have limitations, especially when it comes to identifying mTBI cases. The most common clinical criterion to assess TBI is

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the Glasgow Coma Scale (GCS), which grades the condition of a patient on a scale from 3 to 15 based on verbal, motor, and eye reactions to stimuli [4], [5]. This is however only a qualitative assessment method. Advanced neuroimaging techniques like Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are now widely to assess neurological damage, but these are limited to be used in hospital environments, and are therefore predominantly used on the more severe TBI cases. Electroencephalography (EEG) techniques have the potential for being portable and used in the field at point of injury. Quantitative Electroencephalography (qEEG) has also been demonstrated to discriminate subjects with TBI from healthy subjects with above 80% accuracy [6], [7], [8]. Transcranial current stimulation (tCS), where small AC, DC or other waveform currents are used to stimulate the brain, is currently an active research field. The mechanisms, effects and outcomes of tCS as a therapy modality for a variety of conditions are currently actively debated; see for example [9], [10], [11], [12] and references therein. For TBI, there are currently no conclusions on the potential impact of tCS based therapy, but an interest to investigate potential therapy opportunities.

The EmerEEG project, form which we report, aims to lower the threshold for mTBI detection by realizing a portable device for automated qEEG diagnostics at the point of injury. The system is therefore designed to apply a disposable, one-size-fits-all electrode cap and a fully automated electrode montage system. All electrodes should also be possible to configure to both qEEG and tCS operation. The targeted user scenarios and the overall system architecture have been presented in [13], and an automatic TBI risk diagnosis algorithm developed [14]. The risk diagnosis algorithm has been derived using clinically labeled EEG records, and it is based on discriminant analysis of quantitative EEG (qEEG) features after the removal of artifacts. Algorithm testing has confirmed speed and reliability requirements as well as 87 % TBI diagnosis accuracy [14]. In the past, qEEG and tCS have predominantly been done by separate devices, and operation have relied on the operator to switched manually electrode connections between an EEG device and a tCS system. tCS devices have also until recently only been availiable with a low number of channels, for example single channel, eight channels or 1+4 drain-source channels. For improved "high definition" delivery and distribution of tCS current, it is of interest to have move electrodes, and to enable individual current settings in all channels. Some new devices, such as the Starstim32 from NeuroElectrics exemplifies the emergence of a new generation of devices supporting digitally configurable hybrid qEEG/tCS electrodes for multiple channels [15]. The current EmerEEG system is one of the first to realize a portable, remotely configurable 32 hybrid channel combined qEEG and high-definition tCS system intended for field use at point of injury.

2. Instrument design

Figure 1 illustrates the EmerEEG system. The main component is the Head Device, which contains the complete qEEG and tCS system. The Head Device runs on batteries, and is controlled by a portable server. The server is integrated in the head device, and communicates by WiFi to a control unit. Battery operation removes the need for external power supplies, and hence eliminates both potential risks and noise caused by the connections to power lines during operation in general and in particular during EEG measurements. The system also includes an online server and an interface for a

telemedicine center, thereby making it possible for EEG clinicians to assess EEG readings live from the scene of injury. The system is described in more detail in [13].
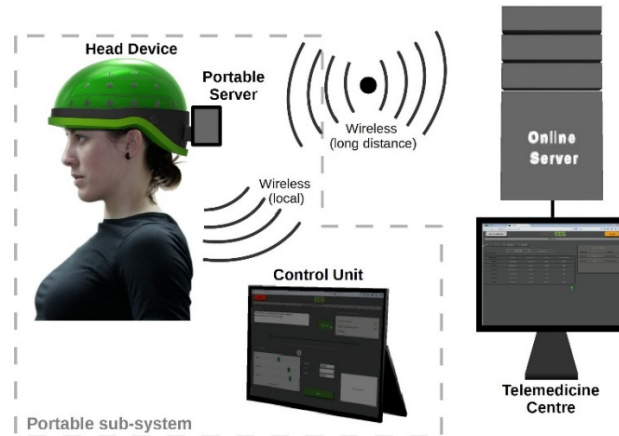

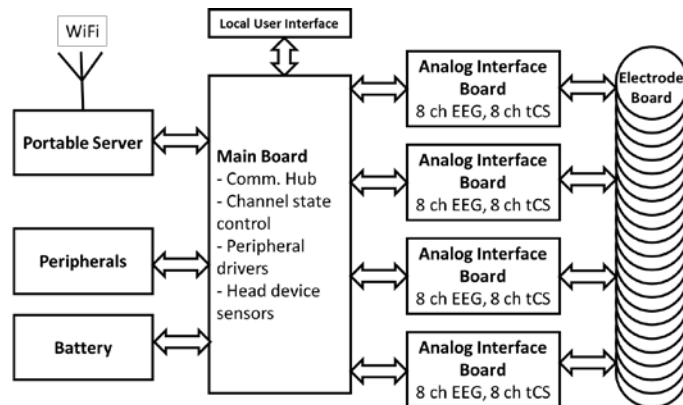**Figure 1**: EmerEEG system concept. From [13].

Figure 2: Instrumentation architecture for the 32 channel, individual configurable, combined qEEG and HD-tCS system.

The overarching instrument architecture for the fully configurable combined qEEG and HD- tCS EmerEEG system is presented in Figure 2. While qEEG requires ultra-senstive measurements in the micro Volt (μV) domain, the driving voltage in tCS is seven orders of magnitude larger (~40 Volts). It is therefore necessary to physically isolate the EEG read-out circuitry by a micro-miniature mechanical relay on each of the front-end electrode boards. A high-impedance buffer on the electrode board reduces noise and parasitic effect caused by wiring, ensuring integrity of the weak EEG signals, and even supports EEG measurements in high impedance conditions, for example using dry electrodes.
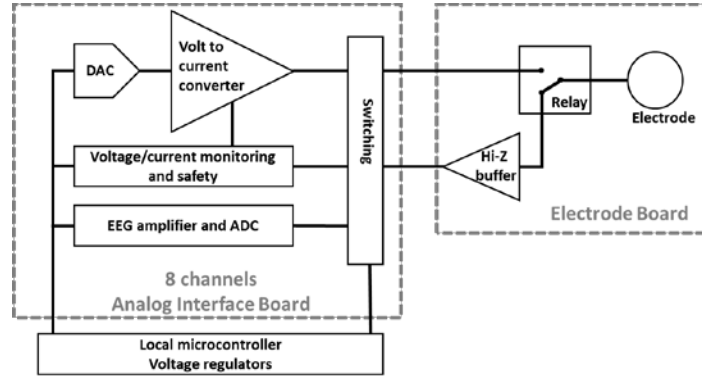
Figure 3: Electrode node configuration.

The complete single channel combined qEEG and tCS electronic design is shown in Figure 3. Eight electrode EEG readout and tCS driver circuit channels are integrated on a single Analog interface board centered around a Texas Instruments ADS1299 8-channel bioamplifier circiut [16]. This design makes it possible to individually define all electrodes into one out of five different measurement configurations: 1) EEG measurement, 2) EEG ground, 3) EEG reference, 4) tCS source, 5) tCS drain. The design also allows simultaneous EEG and tCS operation on different channels. The EEG system can use both dry and wet electrode technologies, but only wet electrode technologies are suitable for tCS for safety reasons. The Main board is responsible for organizing the data streams from the different EEG channels. The Main board microcontroller organizes and forwards raw data to an Odroid U3 based Portable server integrated in the head device. The Portable server, running Linux, can store and forward measurements, and communicate with the portable command interface via WiFi.
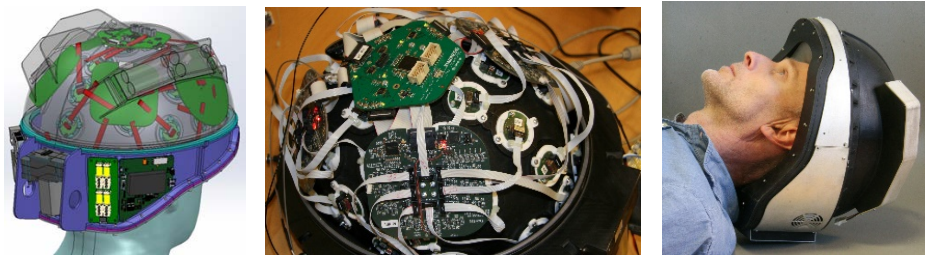

Figure 4: Head device CAD design (left), electronics assembly (middle) and the fully integrated head device (right).

The head device physical prototype has designed using 3D CAD tools and rapid prototyping to realize the mechanical structure holding the circuit boards and other components, see Figure 4. The four Analog Interface Boards are located around the head device, and the Main board can be seen in the middle in Figure 4. A number of head device support components have been placed in the lower rear part of the helmet design. This includes the Portable server a power supply board. A pump and pneumatic controls are also integrated to facilitate the actuation of the disposable one-size-fits-all elastic membrane with integrated electrodes.

3. Results

The integrated head device has been tested in both EEG and tES settings in end-to-end configuration where all device control and all results have been carried out via the external control unit or via the telemedicine interface, confer **Figure 1**. Tests verified that the head device was able to collect, organize and forward EEG data at rates up to the targeted 1 kHz with 32 channels in parallel. Likewise, it was confirmed that the system could configure all channels individually to act at tCS source or drain electrodes. In current source mode, all electrodes could supply up to 2 mA current as targeted. The current was supplied according to pre-defined waveforms, thereby confirming that the system can work in DC, AC or any software configurable or random waveforms up to 1 kHz current supply frequency.

In EEG setting, the system has been tested using wet electrodes to verify signal sensitivity, but a clinical device evaluation has been beyond the scope of the present project. A protocol was carried out and repeated to identify basic features of EEG and electrooculographic (EOG) movement. The 3 min protocol consisted of a duplication of the following activities i) Close both eyes, ii) open both, iii) blink left eye, iv) blink right eye, v) fast blink both eyes, and vi) close and hold eyes shut 30 sec. Whereas this test is not a suitable for a complete analysis of the EEG capabilities, it helped confirmed that the instrumentation allowed measurements with sensitivity corresponding to the Texas Instruments ADS1299 bioamplifier circuit [16]. Additional testing of the head device is planned.

4. Conclusions

A fully configurable, 32-channel hybrid qEEG and tCS instrument system has been realized and function tested. All electronics have been integrated and functionality tested in an end-to-end system configuration for in a rapid prototype printed head device prototype of a portable system intended for mTBI diagnostics. Additional testing of the device is planned.

5. References

[1]   J. Cassidy, L. Carroll, P. Peloso, J. Borg, H. von Holst, L. Holm, J. Kraus and V. Coronado, "Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury," *J. Rehabil. Med,* pp. 28-60, 2004.

[2]   E. Rickels, K. von Wild and P. Wenzlaff, "Head injury in Germany: A population-based prospective study on epidemiology, causes, treatment and outcome of all degrees of head-injury severity in two distinct areas," *Brain injury,* vol. 24, no. 12, pp. 1491-1504, 2010.

[3]   F. Tagliaferri, C. Compagnone, M. Korsic, F. Servadei and J. Kraus, "A systematic review of brain injury epidemiology in Europe," *Acta neurochirurgica,* vol. 148, pp. 255-268, 2006.

[4]   G. T. B. Jennett, "Assessment of coma and impaired consciousness: a practical scale," *Lancet,* vol. 304, no. 7872, pp. 81-84, 1974.

[5]   J. Pal, R. Brown and D. Fleiszer, " The value of the Glasgow Coma Scale and Injury Severity Score: predicting outcome in multiple trauma patients with head injury," *J. Trauma,* vol. 29, no. 6, pp. 746-748, 1989.

[6]   R. W. Rimel, B. Giordani, J. T. Barth, T. J. Boll and J. A. Jane, "Disability caused by minor head injury," *Neurosurgery,* vol. 9, no. 3, pp. 221-228, 1981.

[7]   R. W. Thatcher, R. A. Walker, I. Gerson and F. H. Geisler, " EEG discriminant analyses of mild head trauma," *Electroenc. Clin. Neuro.,* vol. 73, no. 2, pp. 94-106, 1989.

[8]   R. W. Thatcher, D. M. North, R. T. Curtin, R. A. Walker, C. J. Biver, J. F. Gomez and A. M. Salazar, " An EEG severity index of traumatic brain injury," *J. Neuropsych. Clin. N.,* vol. 13, no. 1, pp. 77-87, 2001.

[9]   J. C. Horvath, J. D. Forte and O. Carter, "Evidence that transcranial direct current stimulation (tDCS) generates little-to-no reliable neurophysiologic effect beyond MEP amplitude modulation in healthy human subjects: A systematic review," *Neuropsychologia,* vol. 66, pp. 213-236, 2015.

[10]   J.-P. Lefaucheur and co-workers, "Evidence-based guidelines on the therapeutic use of transcranial direct current stimulation (tDCS)," *Clinical Neurophysiology,* vol. 128, no. 1, pp. 56-92, 2017.

[11]   F. Fregni and co-authors, "Regulatory considerations for the clinical and research use of transcranial direct current stimulation (tDCS): Review and recommendations from an expert panel," *Clinical Research and Regulatory Affairs,* vol. 32, no. 1, pp. 22-35, 2015.

[12]   A. R. Brunoni, A. H. Moffa, F. Fregni, U. Palm, F. Padberg, D. M. Blumberger, Z. J. Daskalakis, D. Bennabi, E. Haffen, A. Alonzo and C. K. Loo, "Transcranial direct current stimulation for acute major depressive episodes: meta-analysis of individual patient data," *The British Journal of Psychiatry,* vol. 208, pp. 522-531, 2016.

[13]   B. Albert, A. Noyvirt, R. Setchi, H. Sjaaheim, S. Velikova and F. Strisland, " Portable Decision Support for Diagnosis of Traumatic Brain Injury," *Procedia Computer Science,* vol. 96, pp. 692-702, 2016.

[14]   B. Albert, J. Zhang, A. Noyvirt, R. Setchi, H. Sjaaheim, S. Velikova and F. Strisland, "Automatic EEG Processing for the Early Diagnosis of Traumatic Brain Injury," *Procedia Computer Science,* vol. 96, pp. 703-712, 2016.

[15]   "Starstim," Neuroelectrics, [Online]. Available: http://www.neuroelectrics.com/products/starstim/. [Accessed Dec 2016].

[16]   "ADS1299-x Low-Noise, 4-, 6-, 8-Channel, 24-Bit, Analog-to-Digital Converter for EEG and Biopotential Measurements," Texas Instruments, [Online]. Available: http://www.ti.com/lit/ds/symlink/ads1299.pdf. [Accessed Dec 2016].