SYNCHRONOUS RECORDING OF MULTIPLE PHYSIOLOGICAL, TRIGGER AND EXTERNAL SIGNAL TRACES FOR CO-REGISTRATION WITH FUNCTIONAL MRI DATA

Jaroslav Marek[1], Jan Rieger[1,2], Darius Lysiak[1], Tomasz Kaczmarczyk[3], Martin Kanowski[4], Claus Tempelmann[4], and Thoralf Niendorf[1,5]

[1]Berlin Ultrahigh Field Facility (B.U.F.F.), Max-Delbrueck Center for Molecular Medicine, Berlin, Germany, [2]MRI.TOOLS GmbH, Berlin, Germany, [3]Blue Brick Ltd., Lodz, Poland, [4]Department of Neurology, Otto-von-Guericke-University Magdeburg, Magdeburg, Germany, [5]Joint cooperation - Charité Medical Faculty and the Max-Delbrueck Center for Molecular Medicine, Experimental and Clinical Research Center, Berlin, Germany

Target Audience: Basic researchers, neuroscientists, clinical scientists and clinicians interested in resting state fMRI as well as MRI applications which benefit from a co-registration of MR data acquisition and physiological signals.

Introduction: BOLD based functional magnetic resonance imaging (fMRI) is sensitive to changes in blood oxygenation. Temporal correlation of the stimulus paradigm with physiological noise induced by cardiac activity, blood flow, blood pulsation and respiration affects the BOLD signal.[1-3] In current fMRI practice, cardiac motion, blood flow and blood pulsation are commonly dealt with using the electrocardiogram (ECG) for registration of cardiac activity with fMRI data acquisition with the goal to eliminate physiological fluctuation induced voxel-level false-positive rates from brain activation maps. [4] Notwithstanding its utility, ECG based assessment of cardiac activity relies on a single physiological signal only and is commonly limited to the R-wave which only marks the electrophysiological start of the cardiac cycle. Also, monitoring of cardiac activity is often not synchronized with the TTL triggering scheme used in the imaging technique that drives (or is driven) by the fMRI paradigm; let alone that respiratory motion is not covered by ECG recordings at all. Realizing those limitations together with the unmet needs of today's fMRI studies this abstract focuses on the monitoring and tracking of multiple physiological signals including ECG, phonocardiogram, magneto-hydrodynamic effect, pulse oximetry, respiration etc. to examine physiological fluctuations. For this purpose we propose a dedicated physiological logging device that facilitates simultaneous and synchronized recording of multiple physiological signals as well as of the scanner trigger in-/output. To meet this goal we present a stand-alone and plug-and-play device that records physiological signals, non-physiological signals, together with the scanner in/out TTL trigger and stores all these traces in a protocol that can be easily loaded into common fMRI analysis software.

Materials and Methods: The proposed logging device is based on a microcontroller board Olimexino-STM32 (OLIMEX Ltd., Plovdiv, Bulgaria). The board runs on a 72 MHz clock, provides 6 integrated analog and 2 digital inputs/outputs (Figure 1) and can be programmed over Maple IDE open source cross-platform (LeafLabs, LLC, Cambridge, Massachusetts). For recording of multiple physiological signals ECG, phonocardiogram, magneto-hydrodynamic effect, pulse oximetry, respiration capnogram and body temperature inputs are supported by the device. Thus multiple phases in the cardiac cycle can be used for co-registration rather than the ECG's R-wave only. Recording of the scanners TTL trigger in conjunction with an fMRI trigger converter (Siemens Healthcare, Erlangen, Germany) is facilitated by the proposed device. The signal input is realized with BNC connectors. All signals are sampled with 500 Hz sampling rate and stored in a logging file together with a time stamp. Analog input signals are supported in the range from 0 to 5V. A 12bit analog to digital converter (ADC) scales the signal in arbitrary units. Digital input signals need to comply with the 5V TTL logic. For data storage a comma separated value (CSV) format is used. Stored data can be easily retrieved from the device on a USB memory stick or an SD card for the purpose of post-processing. A FAT file system was implemented to enable compliance with a standard PC user. To provide user convenience the device is positioned directly at the scanner console. The efficacy and the applicability of the proposed device have been examined in fMRI sessions. For this purpose the scanners TTL trigger, phonocardiogram output (EasyACT, MRI.TOOLS GmbH, Berlin, Germany) and an in-house built respiration monitor utilizing a pressure sensor (Freescale Semiconductor, Inc., Denver, Colorado) were connected to the logging device. The signals were recorded during a 60 min fMRI session. The basic scheme of the setup is illustrated in Figure 2. For fMRI an EPI sequence generating a TTL trigger for each TR (TR=3000 ms) was used on a 7.0 T whole body MR system (Magnetom, Siemens Healthcare, Erlangen, Germany).

Figure 1: The stand-alone logging device is based on a microcontroller board Olimexino-STM32 with a 72 MHz clock. The board allows acquisition for up to 6 analog and 2 digital inputs. A front panel display shows the name of the currently logged file. Relatively small size (dimensions 17x13x20cm³, weight 1kg) of the device makes it easy to transport.

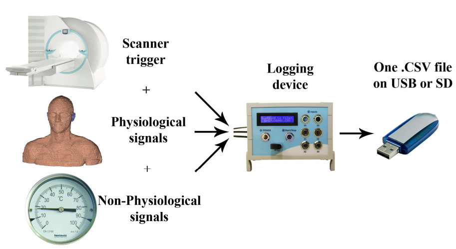

Figure 2: Basic scheme of the setup proposed signal recordings with the logging device. All input signals are simultaneously recorded and stored in a logging file. Samples are acquired with the same sampling rate. Data are saved in Comma separated value (CSV) format to USB or SD memory using a FAT file system.

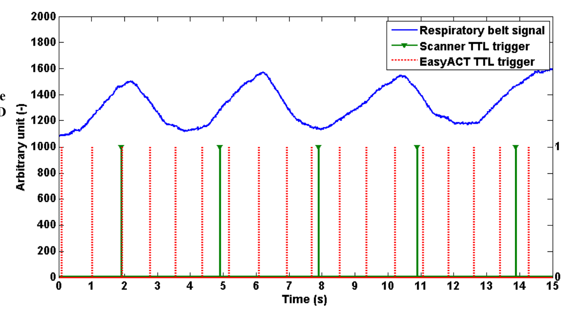

Figure 3: 15s segment of recordings of physiological traces using the logging device during fMRI with standard EPI (TR=3000 ms, TE =30 ms). The TTL trigger (green line with triangles) is sent by the MR system every 3000 ms. Simultaneous acquisition of phonocardiogram induced trigger pulses which embody cardiac activity (red dotted line) and respiratory motion detected by pressure belt representing respiration (blue) are displayed. The patient was in a rest state (heart rate = 72bpm, respiratory rate 14 respiratory cycles per minute). Two digital and one analog input were used simultaneously.

Results: The acquisition of multiple physiological signals throughout a 60 min+ fMRI exam is feasible. The sampling rate is sufficient to acquire data from multiple digital and analog inputs. The generated file size was 50 MB. Each file name was generated based on a previous last file number on USB or SD memory. For ease of use the filename is shown on the display of the logging device and can be incorporated into the name of the imaging protocol used for the fMRI session. Figure 3 displays a 15 s segment of recordings derived from a fMRI setup (EPI BOLD imaging, TR = 3000 ms, TE = 30 ms,). The TTL trigger interval was evaluated using a sliding window approach with a duration of 1 min and was found to be exactly 3000 ms which is in perfect agreement with the fMRI paradigm and repetition time used for BOLD weighted EPI acquisitions.

Conclusion: A device for synchronous logging of physiological traces, the scanner TTL trigger input/output as well as of any arbitrary external signal has been proposed and developed. Its practical applicability has been examined in long term fMRI sessions. The device allows up to 6 analog and 2 digital inputs and stores the data in a standard file format onto a USB stick or an SD card. The device provides a small size format together with ease of use, is portable and hence can be shared among different scanners or groups. The device supports fMRI studies and is in particular suited for resting state fMRI by facilitating co-registration of fMRI data with physiological signals with the goal to compensate - if not eliminate - physiological noise induced signal fluctuations This includes correction of blood and/or CSF pulsation induced artifacts in diffusion weighted and micro-structural MRI of the brain. Prospective or retrospective correction of cardiac activity, blood flow or blood pulsation induced motion artifacts which frequently occur in cardiac MRI or MR angiography present another application area for the proposed logging device.

References: 1. Napadow V. et. al.; NeuroImage 42 (2008) 2. Birn R. M. et al., NeuroImage 31 (2006) 3. Chang C. et. al., NeuroImage 47 (2009) 4. Purdon P.L., Weisskoff R.M., Hum Brain Mapp 6 (1998)