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Multisensory Stimulation Framework for BCI-based Communication in the ICU

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***Introduction**:* Patients in the intensive care unit (ICU) often suffer from delirium, a mental condition that involves disorganized thinking, general confusion, and sometimes, hallucinations. Caretakers screen for delirium regularly since it affects 2 out of 3 hospitalized patients and is correlated to morbidity in the ICU [1]. The screening process requires verbal or physical methods of communication (e.g. eye blinks or hand squeezing); however, endotracheal tube and mechanical ventilators as well as traumatic brain injuries may prevent patients from communicating effectively. Brain computer interfaces (BCI) could potentially help patients who lack the motor control necessary for basic forms of communication. In this work, we present a multisensory stimulation framework for multi-modal BCIs.

***Materials**:* EEG data acquisition is performed with g.USBAmp and MATLAB. Stimulus control is performed by a Beaglebone Black. The physical interface of the stimulation module is comprised of C-3 tactors (tactile), headphones (audio), and 5x5 LED arrays (visual). Visual and tactile stimuli are driven by a Xilinx Spartan3E FPGA. The audio stimulus is driven by a USB DAC.

***Methods**:* The proposed system enables the user to communicate through visual, auditory, and tactile stimulation. Figure 1 shows the system diagram of the stimulus framework. A Beaglebone Black is used to control the stimuli and communicate with the main BCI application. The network interface is implemented using OpenDDS, a real-time publish-subscribe communication module. The visual stimulus is delivered using a set of LED arrays (4 channels) driven by a platform with a FPGA. The BCI developer can configure run-time frequency, pattern, and brightness with pulse width modulation (PWM) for each stimulus channel. Similarly, the tactile module is driven by the same FPGA, thus allowing users to configure and send vibration waveforms to the C-3 tactors (4 channels). Because of the FPGA size limitations, the audio stimulus module is driven by USB DAC. To satisfy the need for accurate stimulus timings, the hardware sends precise start-of-stimulation events (triggers) to the data acquisition component. In the visual and tactile modes, the FPGA outputs a direct trigger signal to the DAQ. In the audio mode, we implemented an external analog circuit that detects a non-audible high-frequency tone embedded in the sound presented to the user. Matlab and C++ APIs were developed to control the stimuli from BCI applications.

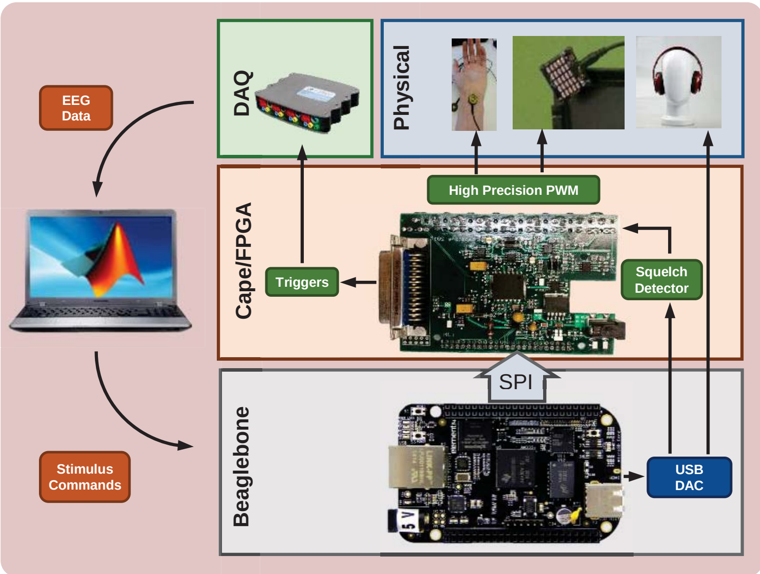

***Figure 1**: System diagram of multimodal stimulation framework.*

***Results and Discussion**:* Trigger timings were all below EEG sample period (2 ms). Visual and tactile stimuli were tested under a binary communication setting with 98% accuracy for visual (3 seconds of SSVEP stimulation) and 70% accuracy for tactile (1 min oddball paradigm [2]). The testing involved asking the users questions from the confusion assessment test. A GUI was developed to run the prototype ICU application.

***Significance**:* By providing a means for physicians to communicate with ICU patients who are unable to speak, or even move, our system could potentially enable the diagnosis of delirium in patients who were unable to be diagnosed before. Furthermore, our multimodal stimulation framework can be used with different BCI applications due to its portability and general communication interface.

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