Preliminary study on SSVEP-based BCI with stimuli generated on a typical computer screen

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Brain-computer interfaces based on SSVEP (steady-state visual evoked potentials) are traditionally built using professional-grade light emitting devices. Accurate, portable and customizable stimulator is desired for such application. The goal of this study is to increase the practicability, portability and ubiquity of an SSVEP-based BCI for daily use.

We present a preliminary study on adapting SSVEP-based BCI to work with customer-grade monitors. The modified system would make users benefit from the lower price of BCI set, as well as make the BCI uncomparably more customizable and facilitate fast prototyping. However, some limitations must be addressed and dealt with, associated mainly with limited set of available frequencies, due to the finite refresh rate of LCD screen.

There are several limitations: limited number of producible frequencies, large pixel response time, more advanced and sensitive detection algorithms required. LCD display parameters can vary widely from device to device.

SSVEP-based BCI with LCD display

- arbitrary UI customization
- LCD screens are used everywhere
- greater portability and mobility
- lower cost

**Direct Sine Generation**
Similarly to LED-based SSVEP, signal can be generated as a time-sampled analytical waveform. This way, stimuli with frequencies up to half of the monitor’s refresh rate can be generated. However, the significant impact of pixel response time will effectively act as a low-pass filter on the generated stimulus, limiting its applicability for high frequencies.

**Colour modulation**
As an alternative to standard stimuli, SSVEP can be evoked by modulating the displayed colour (hue and saturation) in the HSL color space, while keeping luminosity on a constant level. This technique was reported to ease the feeling of dizziness caused by low frequency flashing objects.

**Frame-Based Encoding**
Rectangular waveform on LCD screen can be generated only for the aliquots of the monitor’s refresh rate. For example, at 60 Hz, one could only generate rectangular waveforms of 30 Hz, 20 Hz, 15 Hz, 12 Hz and lower. However, by concatenating periods of rectangular waveforms with different frequencies, one could reliably evoke the SSVEP with the combined (harmonic mean) frequency.

**Phase-Based Encoding**
In addition to different frequencies, the phase can be added to extend the number of commands in a BCI. User can be presented same frequencies with different phases. Furthermore, elaborate encodings schemes such as Multi-Phase Cycle Coding (MPCC) can be used. MPCC consists of cyclic codewords, which is a combination of multiple phases from an available phase set and flickers at single frequency.

**Dual Sine Stimuli**
In order to fully utilize limited number of available frequencies, it is possible to construct a stimulus as a superposition of two sine waves with different frequencies. It is possible to detect both frequencies in the SSVEP response, as long as the frequencies are at least 4 Hz apart.

**Signal Synchronization**
Signal generation based on multimedia timers, especially on non real-time operating system, cannot provide reliable and stable visual stimuli. Instead, low-level display synchronization and/or double buffering should be used.

Cecotti H., Volosyak I., Gräser A.: Reliable visual stimuli on LCD screens for SSVEP based BCI, 18th European Signal Processing Conference 2010