A Cell-Phone Based Brain-Computer Interface for Communication in Daily Life

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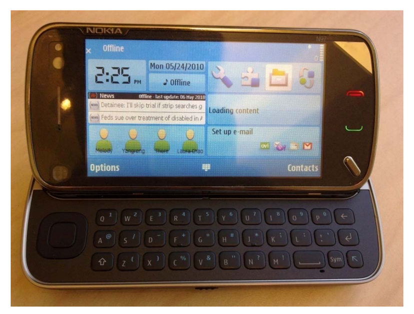
Introduction

BCI community faces lots of challenges to move BCI systems from laboratory demonstrations to real-life and real-time applications. This study aimed to integrate a wearable and wireless EEG system with a mobile phone to implement a steady-state visual evoked potential (SSVEP)-based BCI. The system consists of a four-channel biosignal acquisition/amplification module, a wireless transmission module and a Bluetooth-enabled cell phone. The implications of this mobile and wireless BCI platform were demonstrated in a case study in which wearers' EEG was used to directly make a phone call.

Material & Method

Visual Stimulator

EEG Acquisition Unit

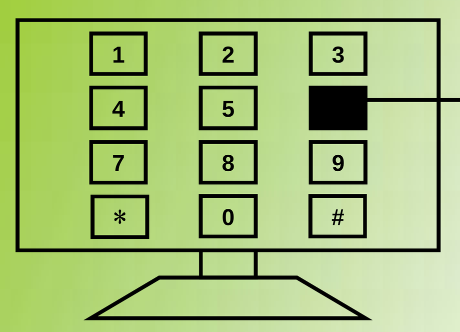


A Cell Phone for Signal Processing

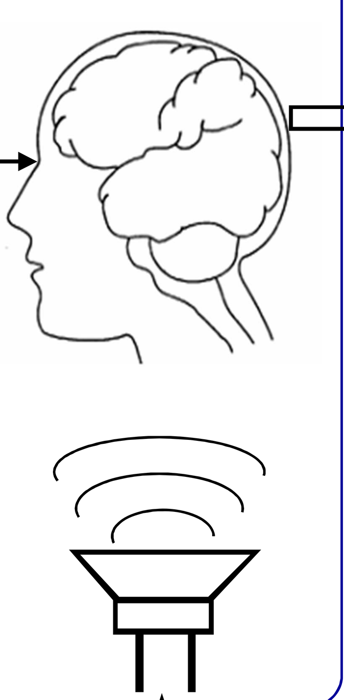
The hardware of this system consists mainly of three major components: a visual stimulator, an EEG acquisition unit and a mobile cell phone for signal processing. Subjects with normal or corrected to normal vision participated in this experiment. Four electrodes embedded in the EEG headband were placed around the O1/O2 area, all referred to a forehead midline electrode.

System Diagram

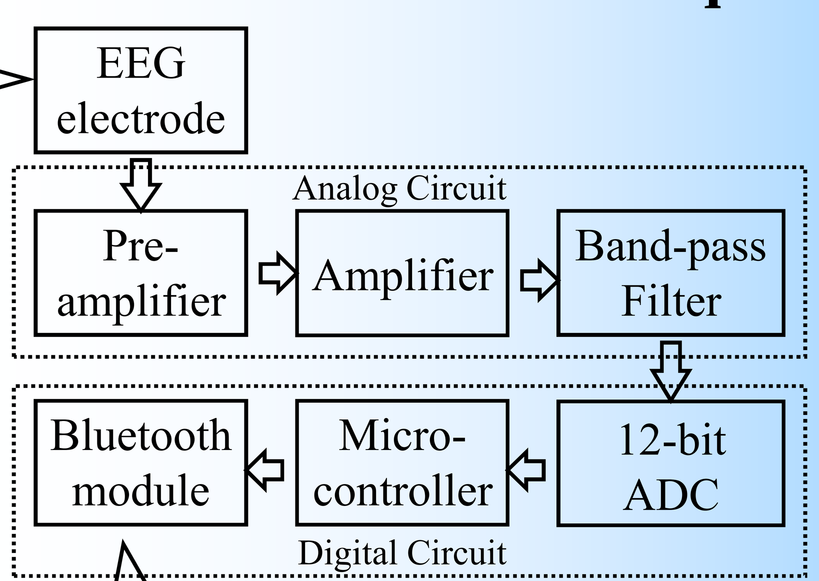
Stimulator



The visual stimulator comprises a 21-inch CRT monitor (140Hz refresh rate, 800x600 screen resolution) with a 4 x 3 stimulus matrix constituting a virtual telephone keypad which includes digits 0-9, BACKSPACE and ENTER. The stimulus frequencies ranged from 9Hz to 11.75Hz with an interval of 0.25Hz between two consecutive digits. The stimulus program was developed in Microsoft Visual C++ using the Microsoft DirectX 9.0 framework.

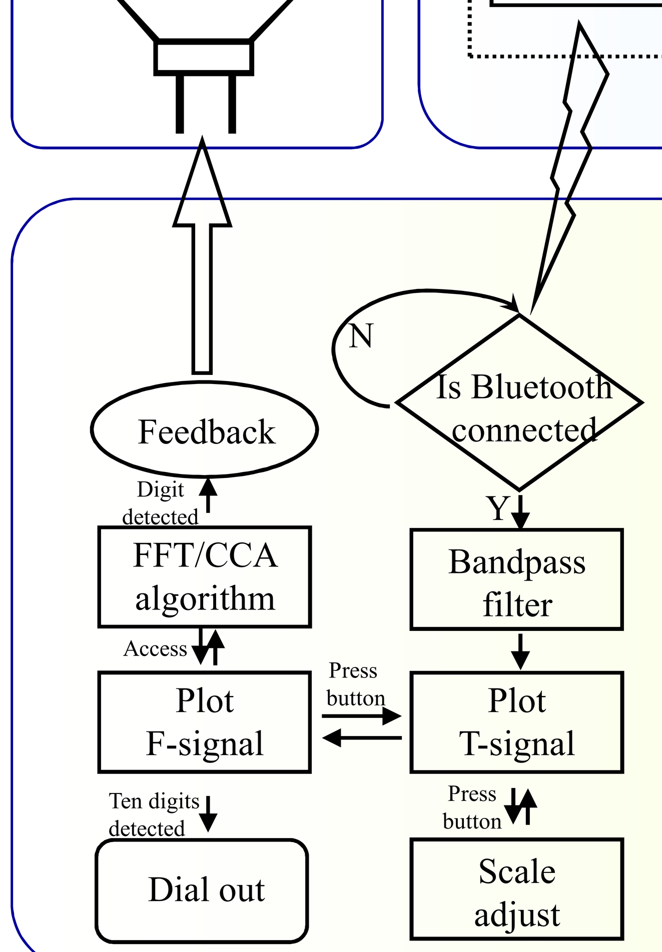


EEG Acquisition Unit



The EEG acquisition unit is a 4-channel wearable bio-signal acquisition unit. EEG signals were amplified (8,000x) by instrumentation amplifiers, Band-pass filtered (0.01-50 Hz), and digitized by analog-to-digital converters (ADC) with a 12-bit resolution and sampling rate of 128Hz.

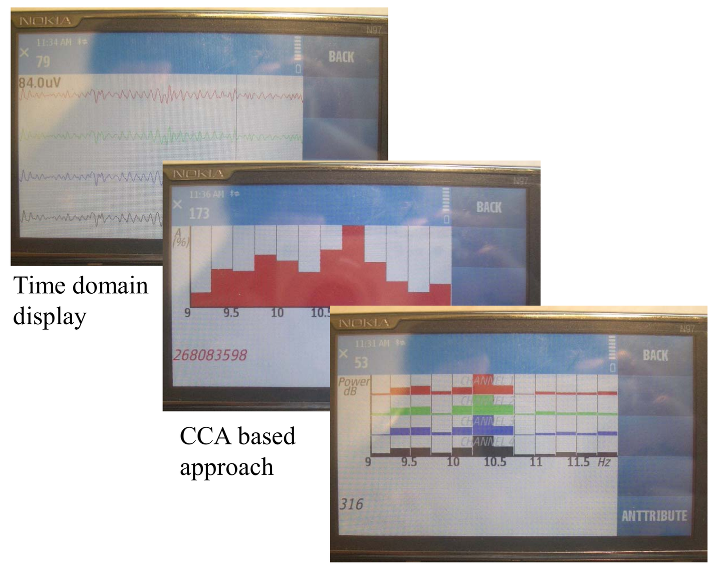
Mobile Cell Phone



The program first initiates a connection to the EEG acquisition unit. Second, four-channel raw EEG data are band-pass filtered (8-20 Hz), and then plotted on the cell-phone's screen every second. The display can be switched to the spectrogram mode. A 512-point FFT is applied to the EEG data using a 4-sec moving window, advancing at 1-sec steps for each channel. To improve the reliability, a target is detected only when the same dominant frequency is detected in two consecutive windows (at time k, and k+1 seconds, k≥4).

Result

Ten subjects completed the task with an average accuracy of 95.9±7.4%, and an average time of 88.9 seconds. Seven of ten successfully input 11 numbers without making any errors. The average ITR was **28.47±7.8** bits/min.



Time domain display

CCA based approach

FFT based approach

Subject	Input length	Time (sec.)	Accuracy	ITR
A	11	72	100	32.86
B	11	72	100	32.86
C	19	164	78.9	14.67
D	11	73	100	32.4
E	17	131	82.4	17.6
F	11	67	100	35.31
G	11	72	100	32.86
H	13	93	92.3	20.41
I	11	76	100	29.95
J	11	66	100	35.85
Mean	12.6	88.9	95.9	28.47

Subject	Online CCA	Online FFT	Offline FFT	**Putative** ITR from off-line FFT			
				Ch1	Ch2	Ch3	Ch4
A	44.79	32.86	36.68	**36.68**	33.58	32.48	29.77
B	46.25	32.86	26.49	**26.49**	10.51	5.91	9.29
F	49.05	35.31	19.43	**19.43**	3.03	3.15	1.92
J	43.18	35.85	15.24	2.2	8.46	**15.24**	4.21
Mean	45.82	34.22	24.46	21.2	13.9	14.2	11.3

Four top performers of the ten subjects were selected to repeat the same tests but their EEG data were decoded using on-line CCA. By using CCA based approach, mean ITR is advanced from **34.22 ± 1.4** bits/min to **45.82 ± 2.2** bits/min for the 4 subjects.

Conclusion

We have designed, developed and tested a truly mobile and wireless BCI for communication in daily life. The BCI consists of

1. A lightweight, battery-powered and wireless EEG headband that was used to acquire and transmit EEG data of unconstrained subjects in real-world environments.
2. A cell-phone that was programmed to carry out signal-processing of the SSVEPs in responses to frequency-encoded visual stimuli, display results and deliver feedback to the users.

The results of this study concluded that all of the participants, with no or little practicing, could make phone calls through this SSVEP-based BCI system in a natural environment.

Acknowledgment

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