A cell-phone-based brain-computer interface for communication in daily life

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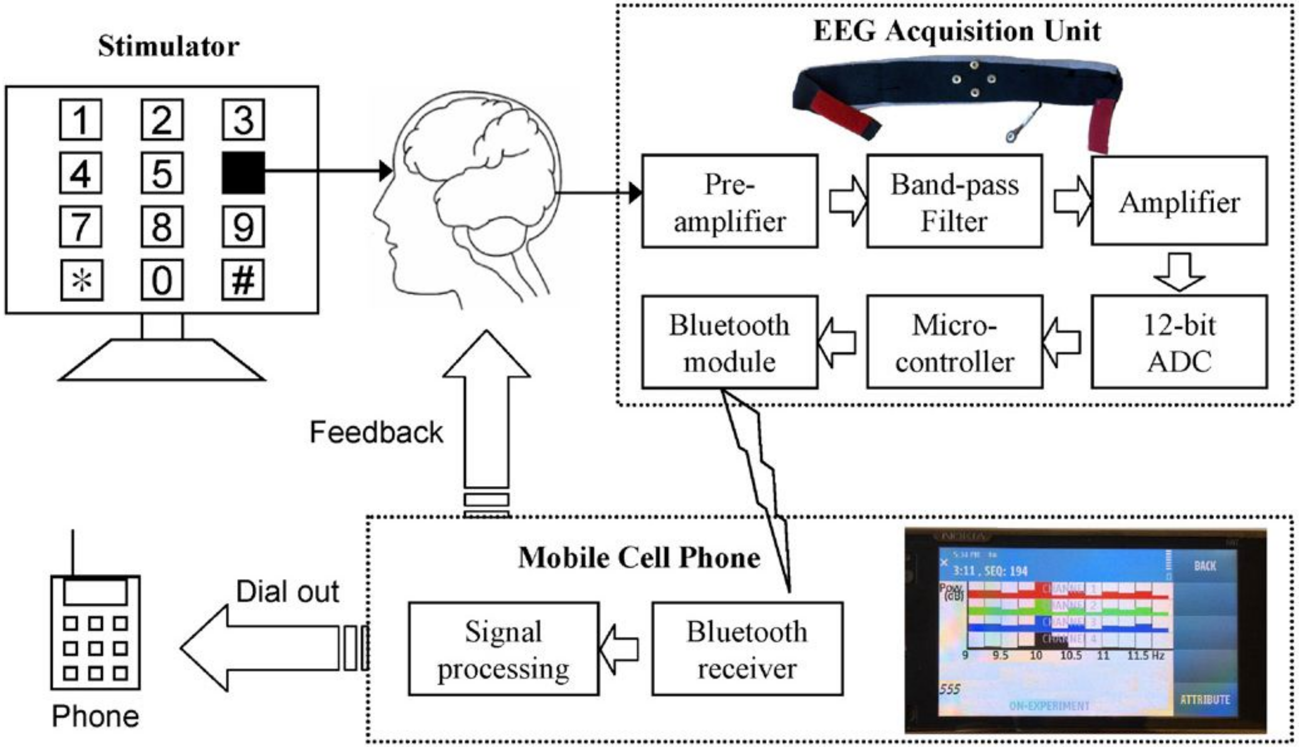
Introduction

- BCI systems acquire EEG signals from the human brain and translate them into digital commands which can be recognized and processed on a computer.
- Although EEG-based BCIs have already been studied for several decades, moving a BCI system from a laboratory demonstration to real-life application still poses severe challenges to the BCI community.
- In real-life applications, BCI systems should not use bulky, expensive, wired EEG acquisition devices and signal processing platforms.
- Several studies have demonstrated the use of portable devices for BCIs.
- Recently, with advances in integrated circuit technology, cellphones combined with DSP and built-in Bluetooth function have become very popular in the consumer market.

Introduction

- If a cell-phone-based BCI proves to be feasible, many current BCI demonstrations (gaming, text messaging) can be realized on cell phones in practice and numerous new applications might emerge.
- This system consists of a four-channel bio-signal acquisition /amplification module, a wireless transmission module and a Bluetooth-enabled cell phone.
- SSVEP is the electrical response of the brain to the flickering visual at a repetition rate higher than 6Hz.
- SSVEP-based BCI, which has recognized advantages of ease of use, little user training and high information transfer rate (ITR), was employed as a test paradigm.
- In an SSVEP BCI, the attended frequency-coded targets of the user are recognized by detecting the dominant frequency of the SSVEP.
- This study implemented and tested both single-channel FFT and multi-channel canonical correlation analysis (CCA) methods for processing SSVEPs induced by attended targets.

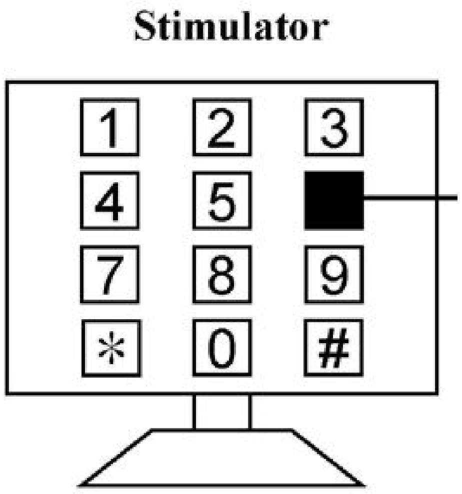
System Architecture



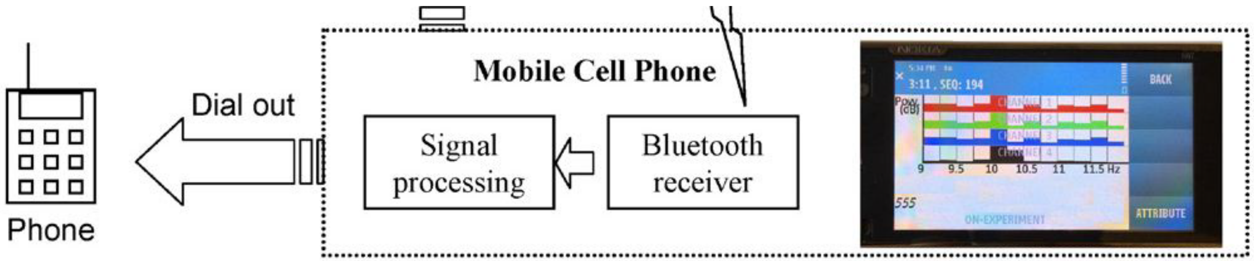
- System hardware diagram
- System software design
- BCI experiment design

System hardware diagram

- The visual stimulator comprises a 21 inch CRT monitor with 4*3 stimulus matrix constituting a virtual telephone keypad which includes digits 0-9, BACKSPACE and ENTER.
- The stimulus frequencies ranged from 9 to 11.75 Hz 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.



System software design



- The signal-processing unit was realized using a Nokia N97 cell phone.
- A J2ME program developed in BorlandJBuilder2005 and Wireless Development Kit 2.2 were installed to perform online procedures including :(1) displaying EEG signals in time-domain, frequency-domain and CCA-domain on the LCD screen of the cell phone, (2) band-pass filtering, (3) estimating the dominant frequencies of the VEP using FFT or CCA, (4) delivering auditory feedback to the user, (5) dialing a phone call
- Users can choose the format of the display btw time-domain and frequency-domain.
- Under the frequency-domain display mode, the power spectral densities of 40channel EEG will be plotted on the screen and updated every second.

System software design

- In the FFT 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.
- In the CCA mode, it uses all four channels of the EEG with a 2 sec moving window advancing 1 sec steps.
- To improve the reliability, a target is detected only when the same dominant frequency is detected in two consecutive windows.
- At the k and k+1 sec, $k \geq 4$ in the FFT mode
- At the k and k+1 sec, $k \geq 2$ in the CCA mode
- The subjects were instructed to shift their gaze to the next target once they heard the auditory feedback.

System BCI experiment design

- The experiments were conducted in a typical office room without room without any electromagnetic shielding.
- Subjects were seated in a comfortable chair at a distance of about 60cm from screen.
- Four electrodes on the EEG headband were placed 2cm apart, surrounding a midline occipital (Oz) site, all referred to a forehead midline electrode.
- The FFT- and CCA-based approaches were tested separately.
- All subjects participated in the experiments during which the cell phone used FFT to detect frequencies of SSVEPs, and four subjects were selected to do a comparison study btw using FFT and CCA for SSVEP detection.
- In the FFT mode, the channel with highest SNR, which is based on the power spectra of the EEG data, was selected for online target detection.
- The EEGs in the CCA experiments were feedback codes for an offline comparison study btw FFT and CCA.

Results

- Tables show results of the SSVEP BCI using FFT and CCA.

Subject	Input length	Time (s)	Accuracy (%)	ITR (bits min^{-1})
s1	11	72	100	32.86
s2	11	72	100	32.86
s3	19	164	78.9	14.67
s4	11	73	100	32.4
s5	17	131	82.4	17.6
s6	11	67	100	35.31
s7	11	72	100	32.86
s8	13	93	92.3	20.41
s9	11	79	100	29.95
s10	11	66	100	35.85
Mean	12.6	88.9	95.9	28.47

FFT-based online test results of the SSVEP BCI in ten subjects

Results

- Tables show results of the SSVEP BCI using FFT and CCA.

Subject	Online CCA	Online FFT	Offline FFT	Putative ITR from offline FFT			
				Ch1	Ch2	Ch3	Ch4
s1	44.79	32.86	36.68	**36.68**	33.58	32.48	29.77
s2	46.25	32.86	26.49	**26.49**	10.51	5.91	9.29
s6	49.05	35.31	19.43	**19.43**	3.03	3.15	1.92
s10	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

CCA-based test results (ITR) of the SSVEP BCI in four subjects. In each row, the bold value highlights the maximum ITR of single channel FFT.

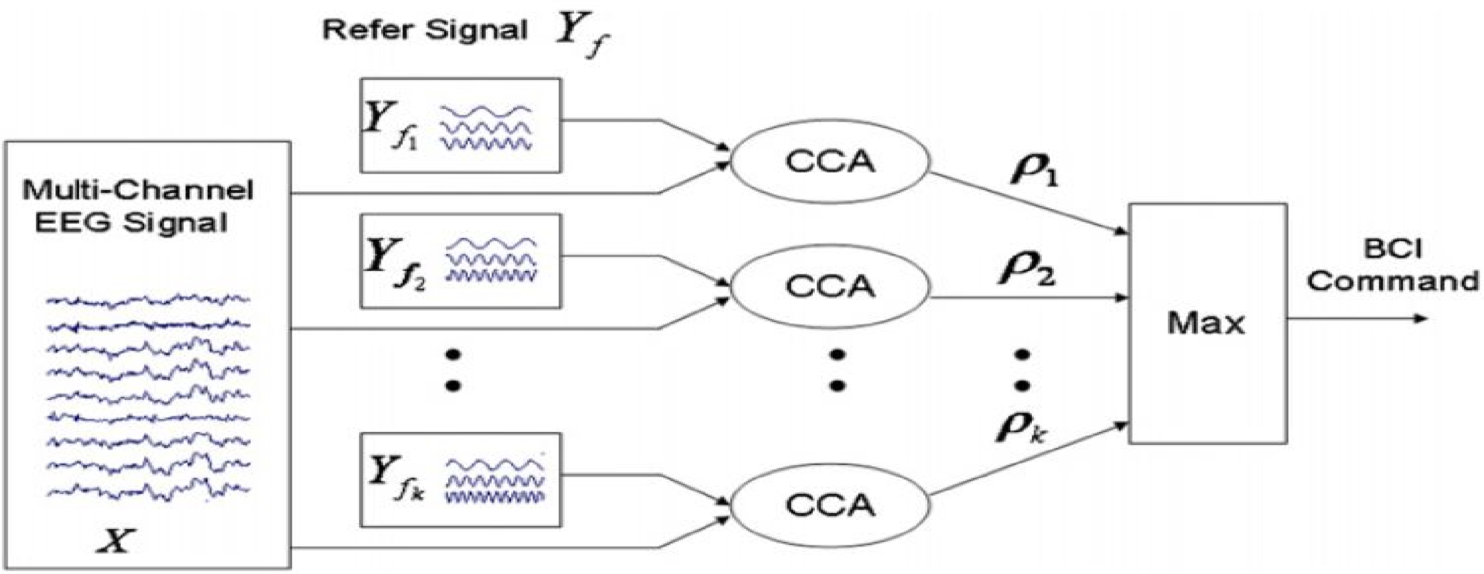
Discussions and conclusions

- This study designed, developed and evaluated a portable, cost effective and miniature cell-phone-based online BCI platform for communication in daily life.
- The practicality and implications of the proposed BCI platform were demonstrated through the high accuracy and ITR of an online SSVEP-based BCI.
- The decline in accuracy and ITR in offline FFT analysis could be attributed to a lack of sufficient data for FFT to obtain accurate results.
- In other words, FFT, in general, required more data than CCA to accurately estimate the dominant frequencies in SSVEPs.

Thank you!

Appendix(CCA)

- Canonical correlation analysis (CCA) is a multivariable used when there are two sets of data, which may have some underlying correlation.
- It finds a pair of linear combinations, for two sets, such that the correlation btw the two canonical variables is maximized.
- Consider two multidimensional random variables X, Y and their linear combinations $x = X^T W_x$ and $y = Y^T W_y$.



An illustration for usage of CCA in EEG signals analysis

Appendix(CCA)

- CCA finds the weight vectors, W_x and W_y, which maximize the correlation btw x and y, by solving the following problem:

$$\max_{W_x,W_y} \rho(x,y) = \frac{E[x^T y]}{\sqrt{E[x^T x]E[y^T y]}}$$

$$= \frac{E[W_x^T XY^T W_y]}{\sqrt{E[W_x^T XX^T W_x]E[W_y^T YY^T W_y]}}$$

- The maximum of ρ with respect to W_x and W_y is the maximum canonical correlation. Projections onto W_x and W_y, i.e. x and y, are called canonical variants.