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Anibal Cotrina

Toward Brain–Computer Interaction in Paralysis

A New Approach Based on Visual Evoked Potentials and Depth-of-Field

Springer

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To people with disabilities

Foreword

When Dr. Cotrina started his doctoral studies in 2012 under my supervision, I was not able to figure the such amount of publications we would have together.

The partnership with Dr. Cotrina resulted in 26 publications spread in journals, conferences, and chapters of book. The final result of his research was the doctoral thesis entitled "A Brain–computer Interface Based on Steady-state Visual Evoked Potentials and Depth-of-Field". And, as an award for his research, Dr. Cotrina got the first place at the Brazilian BCI Competition 2014.

Thus, this book is a compilation of all experience of Dr. Cotrina in the area of BCI (brain–computer interface), which include deep aspects of SSVEP (Steady-State Visual Evoked Potential), Depth-of-field, and stimulation paradigms.

Then, I invite you to enjoy this book, learn about the representation of the visual system on the retina and the visual cortex, know the typical visual evoked potential waveforms, and the difference between covert and overt attention, in order to design a gaze-independent SSVEP-BCI, whose main application is for paralyzed people.

Vitória, Espírito Santo, Brazil
December 2016

Teodiano Freire Bastos Filho

Preface

A brain–computer interface is a system that provides a direct connection between human brain activity and computer-based devices. It generates an alternative channel of communication between the human and his/her environment bypassing the normal output pathways. The applications of BCIs are constantly increasing. It includes communication systems, prosthetics control, rehabilitation, robotics, and interaction of healthy people with their environment. Nowadays, one of the main challenges of this technology is to provide practical and suitable applications for patients with partial or complete paralysis caused by severe neuromuscular disorders. SSVEP-based BCIs are becoming robust systems and are achieving high performance; however, the traditional assessment is not suitable for employing paralysis situation because it demands neck, head, or/and eye ball movements.

In order to take advantage of the potential of the SSVEP-BCI, this book introduces and describes a novel approach of setting visual stimuli based on the optical phenomenon of Depth-of-field. The intention is to offer to users the possibility of selecting a SSVEP stimulus by shifting focus of the eye, instead of perform neck, and/or eye ball movements. This approach was inspired in the photography when it was noticed that any object of a scene can be highlighted by adjusting the focus control of the camera; and not necessarily moving the camera. Then, if two visual stimuli are present in the subject field of view, he/she can highlight one of them (e consequently attenuate the other one) by adjusting the eye focusing. The advantage of the human eye is that focusing is a reflex mechanism. This book is the result of the studies and experiments conducted during my Doctoral and Postdoctoral research at the Intelligent Automation Lab of the Federal University of Espirito Santo. Its content aims to contribute with the development of technologies of human–computer interaction in paralysis situation. It starts with a brief definition of light and how it can modulate the brain signals, and ends showing practical applications, such as the control of a telepresence robot.

The book is organized as follows; In Chap. 1, the problem is contextualized and the purpose of the book is established. Also, a hypothesis is formulated. Chapter 2 provides a theoretical background; starting with the definition of the light and ending with the presentation of a command of a brain–computer interface

originated by a light stimulus. Also, a literature review is dealt including recent relevant works that addressed the application of SSVEP-BCI in patients with paralysis. In Chap. 3, the new approach of setting the SSVEP stimuli based on Depth-of-field phenomenon is presented. Concepts related to the optical phenomenon of Depth-of-field are reviewed, such as defocusing and point spread function. Also, physiological aspects such as the accommodation of the eye mechanism and retinal blur model are addressed. Chapter 4 introduces a demodulation method for extracting frequential features in the context of the SSVEP-BCI based on the Depth-of-field. For this aim, the spatial-temporal spectral response caused by a focused stimulus and a non-focused stimulus was studied. Some experiments are conducted by evaluating and comparing the spectral power of focused and non-focused stimuli to verify if the amplitude of the retinal response is higher for the focused one than for the non-focused one. In Chap. 5, experiments conducted for evaluating the detection of commands associated to focusing mechanism are described. The evaluation is conducted in offline mode to find out the possibilities of employing a SSVEP-BCI based on Depth-of-field in practical situations. Conventional BCI performance metrics were employed. Chapter 6 presents and describes online practical applications of the SSVEP-BCI based on Depth-of-field in communication and control. A speller system and a system for controlling a telepresence robot were implemented. Pilots experiments conducted for evaluating each system are described. Finally, vantages and limitations of the proposal and its future directions in patients with paralysis are presented.

Sao Mateus, Brazil — Anibal Cotrina
November 2016

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Sao Mateus, Brazil — Anibal Cotrina
November 2016

Contents

Acronyms

AAN	American academy of neurology
ALS	Amyotrophic lateral sclerosis
BCI	Brain–computer interface
BPF	Band-pass filter
CAR	Common average reference
CCA	Canonical correlation analysis
CNS	Central nervous system
CRT	Cathode ray tube
DFT	Discrete Fourier transform
DMD	Duchenne muscular dystrophy
ECoG	Electrocorticographic
EEG	Electroencephalographic
EMG	Electromyography signals
EOG	Electrooculography signals
ERD	Events related to desynchronization
ERP	Event-related potentials
ERS	Events related to synchronization
FFT	Fast Fourier transform
FIR	Finite impulse response
fRMI	Functional magnetic resonance imaging
GBS	Guillain-Barre syndrome
HMI	Human–machine interaction
HPF	High-pass filter
ITR	Information transfer rate
LASSO	Least absolute shrinkage and selection operator
LCD	Liquid crystal display
LED	Light-emitting diode
LGN	Lateral geniculate nucleus
LIS	Locked-in state
LPF	Low-pass filter

MEG	Magnetoencephalographic
NPSF	Neural point spread function
PSDA	Power spectral density analysis]
PSD	Power spectral density
PSF	Point spread function
SCP	Slow cortical potentials
SMR	Sensorimotor rhythms
SNR	Signal-noise rate
SSVEP-BCI	BCI based on Steady-state visual evoked potentials
SSVEP	Steady-state visual evoked potentials
TW	Time window
VEP	Visual evoked potentials
VE	Virtual environment