Brain Computer Interface

Christoph Guger

Time Table

Equipment for BCI research
Fundamental concepts
Mounting EEG electrodes correctly
Motor imagery BCI
Real-time analysis of P300: Spelling with the BCI
Controlling a smart home with the BCI
Real-time analysis of SSVEPs: Robot control
Real-time analysis of spikes: Position reconstruction
We need one subject for the P300 spelling experiment
g.tec – “accelerate your biosignal research”

company fields
- bio-engineering, medical electronics (bio-electricity)
- developing and offering hard- and software products for biosignal research
  (single cell activity, EEG, ECoG; muscle cells: ECG, EMG; other tissue: EOG, ...)
- performs user specific adaptations and developments
- mainly based on rapid prototyping environment under MATLAB/Simulink

company description
- private company, located in Graz and Schiedlberg (Linz), Austria
- inter-disciplinary team (biomedical-, telematics engineers, psychologists)
- customers: universities, university hospitals, R&D departments, industry

Brain-Computer-Interface (BCI)

"A system for controlling a device e.g. computer, wheelchair or a neuroprosthesis by human intention which does not depend on the brain's normal output pathways of peripheral nerves and muscles" [Wolpaw et al., 2002].

HCl – Human Computer Interface
DBI – Direct Brain Interface (University of Michigan)
TTD – Thought Translation Device (University of Tübingen)

MATLAB and Simulink environment
### Research Projects

1. **#) EC project: ReNaChip - Synthetic system integration**
   Rehabilitation of a discrete sensory motor learning function

2. **#) EC project: Sm4All – Smart Home for all**
   Brain-Computer Interface for smart home control

3. **#) EC project: RGS – Rehabilitation Gaming System**
   Faster recovery from stroke with games

4. **#) EC project: BrainAble**
   BCI with VR and social networks

5. **#) EC project: Decoder**
   BCI for locked in patients

6. **#) EC project: CSI - Central Nervous System Imaging**

7. **#) EC project: BETTER**
   BCI for Stroke rehabilitation and rehabilitation robots

8. **#) EC project: VERE – Virtual Embodiment Real Embodiment**
   Dissolving the boundary between the human body and surrogate representation in virtual and physical reality.

9. **#) EC project: ALIAS – Adaptable Ambient Living Assistant**
   Robot system interacting with elderly people providing cognitive assistance and social interaction and inclusion

### g.tec – Awards and Prizes

- Winner of the Microsoft Innovation Award 2010
- Winner of the Science2Business Award 2010
- Winner of the Econovius 2009
- Winner of the Fast Forward Award 2008
- Winner of the Research Price of the Austrian society for mountain medicine 2007
- Winner of the Well-Tech Award 2007
- Winner of the European ICT Prize 2007
- Winner of the GEWINN Jung-Unternehmer-Wettbewerb 2006
- Nominated for the Fast Forward Award 2006
- Winner of the GEWINN Award as most innovative company, 2001
- Nominated for the Austrian price of innovation, 2001
- Winner of the Forward Award as most innovative company, 2000

### How to record brain activity for BCI?

#### Functional imaging techniques: FMRI, SPECT, PET

#### Magnetencephalogram (MEG, SQUID)

#### Near Infrared Spectroscopy (NIRS, fNIR)

#### Electrocorticogram (ECoG)

#### Electroencephalogram (EEG)

### Measuring brain electrical activity

**Electroencephalogram (EEG)**

- 1 – 64 (128) channels, 1 µV – 100 µV, DC up to mV-range, 0 – 40 Hz, low signal-to-noise ratio, moderate spatial resolution, high temporal resolution
- Surface electrodes: 8 ...12 mm, mounted with conductive gel/paste

**Electro-corticogram (ECoG)**

- Closely spaced multi-electrode grids or strips applied directly to the cortical surface, electrode diameter ~ 4mm, up to 500 µV, 1 – 100 Hz
- High signal-to-noise ratio, high spatial and temporal resolution
- Highly invasive and limited study opportunities
We built an amplifier that can now be used not only for EEG, but also for implanted electrodes in humans, spike recordings and in vitro setups.

Hardware Development
EEG, ECoG, EMG, EOG, ECG amplifiers
1-128 channels

A. USB based biosignal amplifier
16 integrated 24 Bit ADCs
Floating point DSP
re-referencing
oversampling (~20000 times)
bandpass and notch filtering

B. Mobile device
2-4 AA batteries
1 integrated 16 Bit ADC
wireless data transmission
1 week operation time
TCP/IP remote control

C. Stand-alone device
analog output
combine it to DAQ board (e.g. NI)
resolution
sampling frequency
PCI or PCMCIa board
**g.Hlamp**

256 channels per unit with 4 multi-pole connectors at front side.
Synchronization of 4 units possible to have 1024 channels.
Sampling frequency between 64 Hz and 38.4 kHz, 1 ADC per channel for synchronization.
24 Bit ADC per channel for perfect resolution.
Input range of +/-250mV to measure from EMG, ECG, ECoG, Spikes, EEG down to EPs with only one setting. Therefore no saturation of the amplifier possible.
DC – 6 kHz input frequency range.
Can be synchronized with g.USBamp.
CE and FDA approved.
C API, MATLAB API, Simulink driver and recording software will be available.
Linux and Windows version.
OS 32 Bit and 64 Bit.
Different headboxes for passive or active electrodes or headstages.
16 digital inputs/outputs for triggering with external devices.
Impedance check included.

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**Software Programming Environment**

A. **C++ Application Program Interface (API)**
   - allows to integrate amplifiers into own software under Windows and Linux.

B. **MATLAB API**
   - integrate amplifiers into MATLAB data acquisition and analysis programs.
   - access to all toolboxes (Signal Processing, Neural Networks, …).
   - access to user written M-files.

C. **Simulink Highspeed on-line Processing**
   - amplifier device driver block under Simulink.
   - copy the block into Simulink model and connect the signal processing (S-functions) and paradigm blocks (MATLAB code).
   - just exchange the amplifier device driver and work with the same signal processing blocks.

D. **LabView**
   - amplifier device driver block under LabView.
   - use standard LabView blocks for analysis.

All three options give full access to hardware.
- bandpass, notch settings.
- sampling frequency.
- impedance check.
- …

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**Changes of brain electrical activity and mental strategies**

- **Slow cortical potentials (anticipation tasks)**
  DC-derivation, artifact problem, difficult strategy, feedback method.

- **Steady-State Evoked potentials (SSVEP, SSSEP)**
  Flickering light with specific frequency.

- **Event-related, non-phase-locked changes of oscillatory activity**
  ERD/ERS (motor imagery tasks).
  Changes of mu-rhythm, alpha activity and beta activity over sensorimotor areas,
  imagination of hand-, foot-, tongue- movements.

- **Evoked potentials (focus on attention task)**
  Thalamic gating, various methods of stimulation (visual, tactile, electrical, auditory, …),
  P300.
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Physiological Background – why does it work

Imagination of hand movement causes an ERD which is used to classify the side of movement. The desynchronization occurs in motor and related areas of the brain. Therefore, for analyzing and classifying ERD-patterns the electrodes must be placed close to sensorimotor areas.

CASE STUDY: ERD/ERS based Brain-Computer Interface

BCI in Virtual Environments

AIM:

- tracking subjects responses in the VE by neuro-physiological measurements: building better VE, therapy application for patient with anxiety psychosis, ...
- realization of real-time classification of brain states to control VE by thoughts only: walking through VE

The "Finger Movement Task"

Brisk movement of right index finger
Patient Tom (C4/C5 lesion)

Video: Control of orthosis

Biosignal Analysis and Recording System in VE

• The recording system has to work in noisy environments.
• CAVE system: creates a 3D Virtual World
  TRIMENSION ReaCTor
  3 back projected screens (3m x 2.2m)
  1 floor screen projected by ceiling mounted projector
• 3D effect with shutter glasses

Movie: “Walking through a Virtual City by Thought”

EEG-based "walking" of a tetraplegic in virtual reality

Laboratory of Brain-Computer Interfaces
Graz University of Technology
Austria
Case study: Electrocorpograms, ECoG

Direct Brain Interface, rhythmic activity, Albany, USA

Augmentation of neuronal population activity using a brain-computer interface

Kai J. Miller
Physics, Medicine
Neurobiology and Behavior,
Neural Systems Lab
University of Washington

Basic spectral changes with movement
Real-time representation of cortical activity

Measuring brain electrical activity

Brain Control with Hand Movements

Categorization of the 57 submitted projects

<table>
<thead>
<tr>
<th>Property</th>
<th>Percentage (N=57)</th>
<th>Property</th>
<th>Percentage (N=57)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-time BCI</td>
<td>65.2</td>
<td>Stroke</td>
<td>7.0</td>
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<tr>
<td>Off-line algorithms</td>
<td>17.5</td>
<td>Spelling</td>
<td>19.3</td>
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<tr>
<td>P300</td>
<td>29.8</td>
<td>Wheelchair/Robot</td>
<td>7.0</td>
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<td>SSVEP</td>
<td>8.9</td>
<td>Internet/VR</td>
<td>8.8</td>
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<td>Motor imagery</td>
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<td>Control</td>
<td>17.5</td>
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<tr>
<td>EEG</td>
<td>75.4</td>
<td>Platform/Technology</td>
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<td>ECoG</td>
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<tr>
<td>NIRS</td>
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P300 – Approach (EEG)

The 6 x 6 matrix speller, single character flash

concentrate on „W“
Individual character intensifies for 60ms with 10ms between each intensification
Performing real-time BCI experiments
Hands on seminar

Spelling with the brain-computer interface
q.tec - Austria

Japanese Speller version

The Virtual Reality apartment

Operation of a P300-based brain computer interface by individuals with cervical spinal cord injury

Designed by Chris Groenegess, Mel Slater
### Changes of brain electrical activity and mental strategies

- **Slow cortical potentials (anticipation tasks)**
  DC-derivation, artifact problem, difficult strategy, feedback method
- **Steady-State Evoked potentials (SSVEP, SSSEP)**
  - Flickering light with specific frequency
- **Event-related, non-phase-locked changes of oscillatory activity**
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### Steady-State Visual Evoked Potentials (SSVEP)

<table>
<thead>
<tr>
<th>Frequency of stimulation</th>
<th>Brain response</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ... 2 Hz</td>
<td>transient (single) VEP</td>
</tr>
<tr>
<td>3 ... 5 Hz</td>
<td>undefined response</td>
</tr>
<tr>
<td>6 ... 24 Hz</td>
<td>SSVEP</td>
</tr>
</tbody>
</table>
Steady-State-Evoked Potentials

Higher Frequency (e.g. 17 Hz)

Lower Frequency (e.g. 14 Hz)

EEG Power Spectrum

Steady-State Visual Evoked Potentials (SSVEP)

up to 48 different frequencies possible!

Comparison of gel and dry electrodes

Normally, EEG is recorded with gel based electrodes

Low electrode-skin impedance important

Passive electrodes: skin must be abraded to reduce the impedance

Active electrodes: electrode gel is injected between the electrode material and the skin

Main disadvantages of gel based systems are:

• the long montage time
• the need to wash the user's hair after the recording
g.tec developed active and dry EEG electrode

g.SAHARA electrode system (patent pending) consists of an 8 pin electrode made of a special golden alloy.

Pins have sufficient length to reach through the hair to the skin.

Golden alloy and the 8 pins reduce the electrode-skin impedance.

Electrode itself can be connected with a clip to the active electrode system on top of it.

EEG recordings are performed at frontal, central, parietal and occipital regions of the head.

Mechanical system is required that holds the electrode to the skin with a constant pressure at every possible recording location.

EEG electrodes are typically positioned according to the International 10/20 System.

g.tec hence developed the 2nd generation of the g.GAMMAcap, with a total of 160 positions according to an extended 10/20 system, to allow a very flexible electrode montage.

BCI AND DRY ELECTRODES

BCI use P300, motor imagery or steady-state visually evoked potentials (SSVEP) measured with the electroencephalogram (EEG) to control external devices.

Evoked potentials, event-related desynchronization, power spectrum accuracies were calculated for dry and gel based electrodes to compare them.

www.gtec.at
Discussion:
First dry electrode system that works for motor imagery, SSVEP and P300 (same accuracies reached for all)
Whole frequency range available: 0.1-40 Hz
First dry electrode system that covers extended 10/20 system on frontal, central, parietal and occipital sites
More low frequency components in the EEG spectrum below 3 Hz
Careful montage required and more sensitive to surrounding noise
Group studies submitted in March 2011 to Journal of Neural Engineering and BCI conference in Graz 2011.

Progress in BCI research
September 1998
First 100% accuracy BCI session with CSPs in Graz (160 trials)
7 days of training

September 2008
~73% of population can control BCI system with 100% (based on 85 subjects)
5 minutes of training
Guger et al., Neuroscience Letters, 2009
TODAY: SSVEP, P300 and motor imagery can be shown within one workshop.

Biomedical Engineering Lectures in PDF format

Tutorial contain theory and tasks (measurements, analysis,…)
Solutions in a second manual
Very useful in education and to get into the field
EEG
ECG
Eps
BCI

Our co-operations partners

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