Non-Invasive Brain-Controlled Robots

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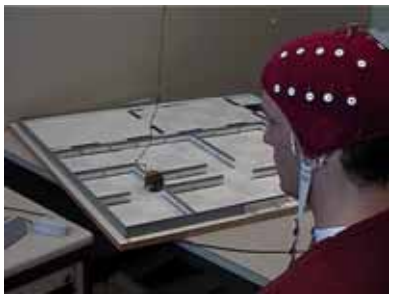
Outline

- Brain-controlled robots: A short overview
- May I Help? Adaptive Shared Autonomy
- Run Fast! — Very High Frequencies
- Wait for me! — On-Line Learning
- You got me wrong! — My brainwaves say
  Key to dependable interaction?
- Conclusions: Towards Brain Technology

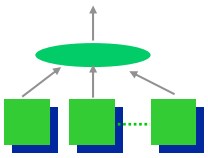
Brain-Controlled Robots

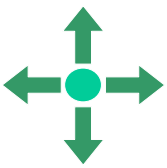
use of ***non-invasive*** brain electrical activity to directly control the movement of robots or prosthetic devices



(Science 03)
Scientific American 50

BCI Architecture





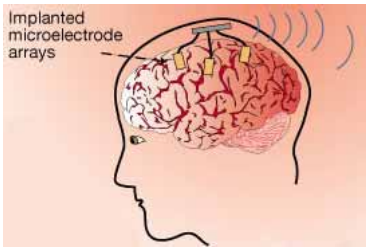
Acquisition System → **Feature Extraction** Digital Signal Processing → **Feature Classification** Statistical Classifier → **Action Generator**

Feedback

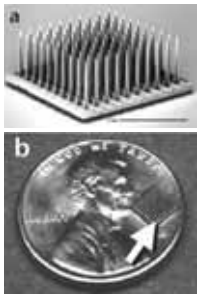
BCI Modalities

- *Direct Invasive Recordings*

  Activity of single neurons measured from microelectrodes surgically implanted in the cortex

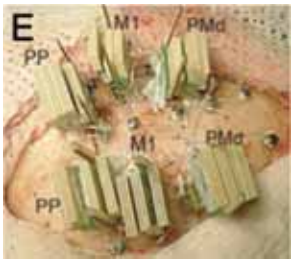


(Nicolelis, Nature 01)



(Donoghue, Nature Neurosci 02)

Invasive BCI



(Nicolelis, PNAS 03)

- *Parallel distributed neural information processing*

  motor parameters are encoded by ensembles of neurons

Multi-electrode recordings

↓

Single-unit spike sorting → Predict monkey's intent → Move robot arm

BCI Modalities

Direct Invasive Recordings

- *Electrocorticogram (ECoG)*
  Recordings of neural signals from the cortical surface of the brain. Electrodes do **not** penetrate cortex

(Leuthardt et al., J Neural Eng 2004)

Non-Invasive BCI

Non-Invasive Electroencephalogram (EEG)

- *Evoked Potentials*
  EEG waveforms generated automatically in response to external stimuli (visual, auditory, …)

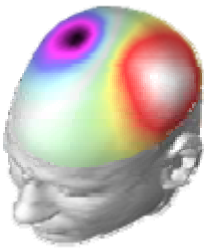
- *Spontaneous Activity*

Adaptive Brain Interface: Basic Principles

- *Asynchronous* operation
  - spontaneous and self-paced decisions, no external cues
  - fast response, ½ second
- *Mutual* learning process
  - statistical classifier
  - increase likelihood of success and enable rapid mastering
- Tasks induce *different EEG rhythms* over local cortical areas
  - mixed of motor-related and cognitive mental tasks
  - each subject chooses 3 out of 7 possible tasks

Signal Processing

- 96 Power Spectral features (band 8-30 Hz)
- 1 second window
- 62.5 ms (16 times/second)



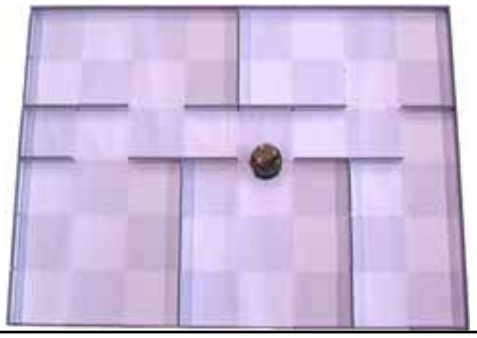
Gaussian Classifier

- Every unit represents a prototype of one of the mental tasks
- Network's output to the current EEG sample:
  - ⇒ class with the highest probability
  - ⇒ "unknown"
- BCI responds every *½ second*:
  Average of the output to 8 consecutive EEG samples
- During training units are
  - ⇒ pulled towards the EEG samples they represent
  - ⇒ pushed away from EEG samples of other classes
- Units give a direct interpretation of the brainwaves that represent their mental task and differentiate it from others

Brain-Actuated Control of a Mobile Robot

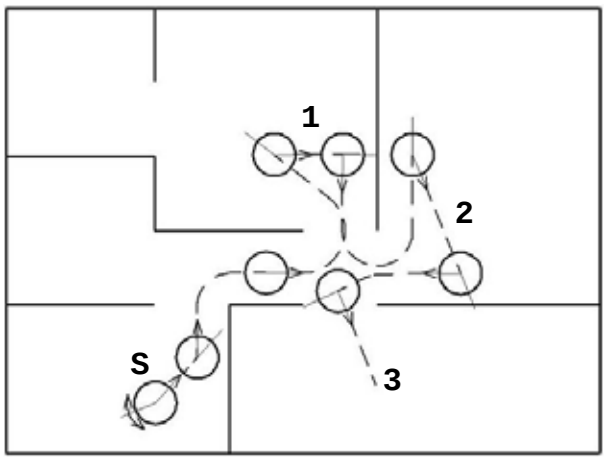
Users address the task at high level and all the low level details are handled automatically:

behavior-based architecture



Experimental Results – I

Qualitatively
good trajectories



Experimental Results: Execution Time (sec)

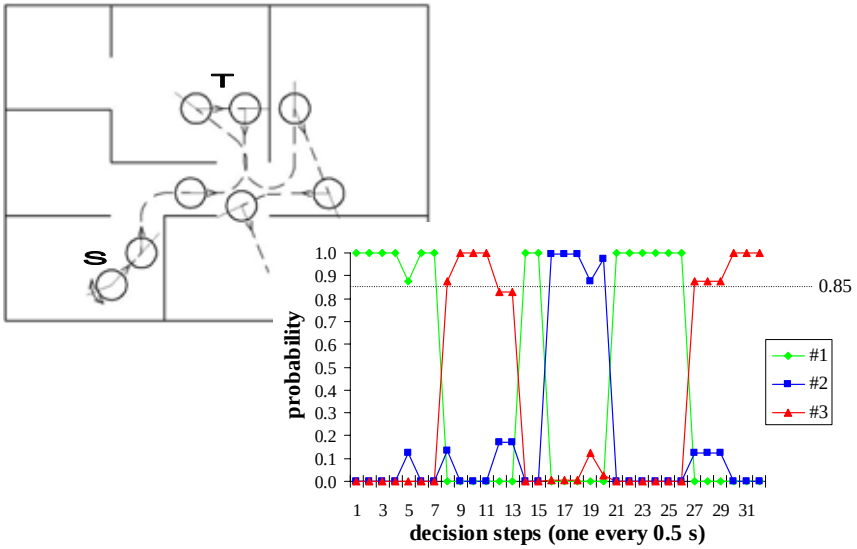
Subject 1
Relax, Left, Cube

Trial	Mental	Manual	Ratio
1	149	124	0.83
2	183	135	0.74
3	191	129	0.68
Average	***174***	***129***	***0.75***

Subject 2
Relax, Left, Right

Trial	Mental	Manual	Ratio
1	219	156	0.71
2	189	155	0.82
3	175	117	0.67
Average	***194***	***143***	***0.73***

Experimental Results: Fast Decisions



Conclusions … and Challenges

- Non-invasive neuroprostheses, combination of:
  - Asynchronous protocol for EEG analysis,
  - Machine learning techniques,
  - AI robotics.
- Encouraging … but

A Look behind MAIA's Veil

Asynchronous approach.

3 mental tasks (forward, turn left, turn right).

The brain-actuated wheelchair incorporates advances in

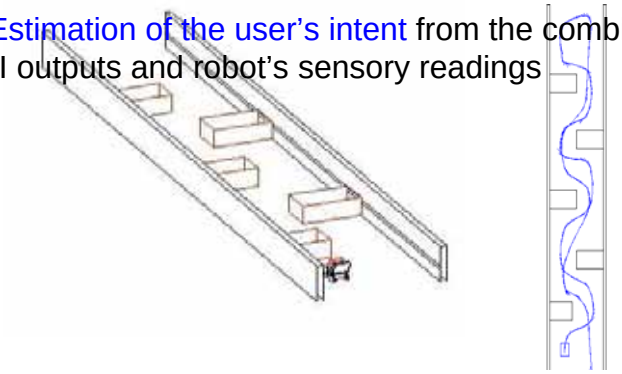
- *adaptive shared autonomy,*
- *high frequencies,*
- *online adaptation.*

I. May I Help? Adaptive Shared Autonomy

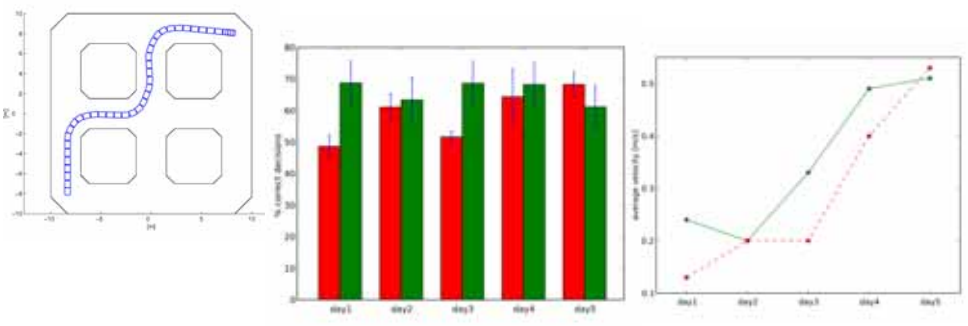
Marnix Nuttin, **Gerolf Vanacker**, & **Johan Philips.** *KU Leuven*
Eileen Lew. *IDIAP*

The intelligent controller relieves users from low-level tasks without sacrificing their cognitive superiority and adaptability

- Estimation of the user's intent from the combination of BCI outputs and robot's sensory readings



Adaptive Shared Autonomy (cont)

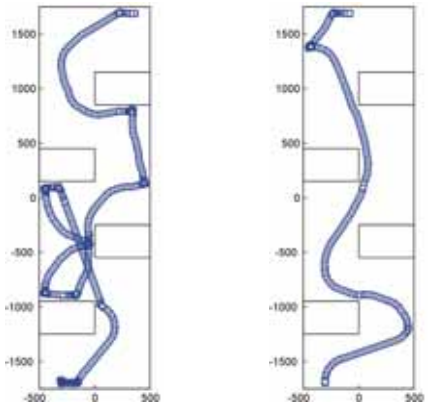


Percentage of trials in which the goal was reached

day	overall (all sessions)	sessions without filtering	sessions with filtering
day 2	60.00%	40.00%	80.00 %
day 3	80.00%	66.67%	85.71%
day 4	70.00%	60.00%	80.00%
day 5	80.00%	100.00%	60.00%

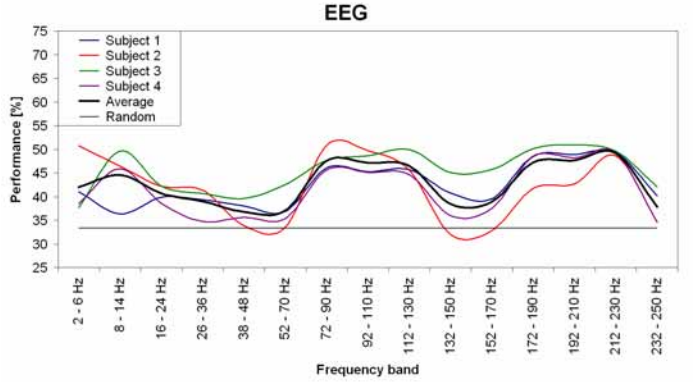
Adaptive Shared Autonomy (cont)

Adaptive level of intelligence so as to complement the user's capabilities at any moment



II. Run Fast! — Very High Frequencies

Ferran Galán & **Pierre Ferrez.** *IDIAP*
Rolando Grave & **Sara Gonzalez**. *Geneva University Hospital*

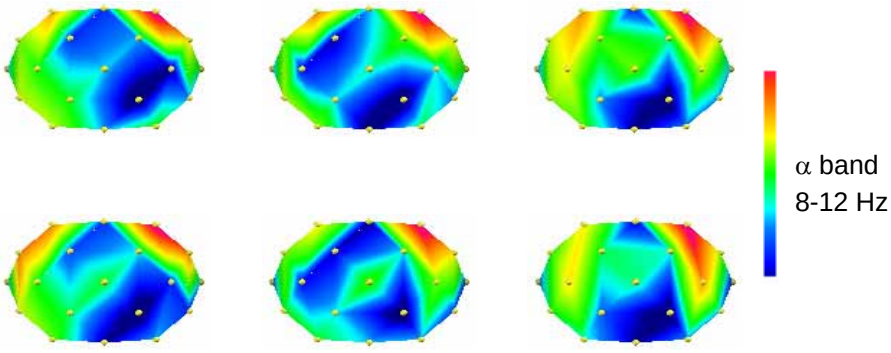


- 70 – 130 Hz band and 170 – 230 Hz band outperform the “traditional” 2 – 40 Hz band

III. Wait for me! — On-Line Learning

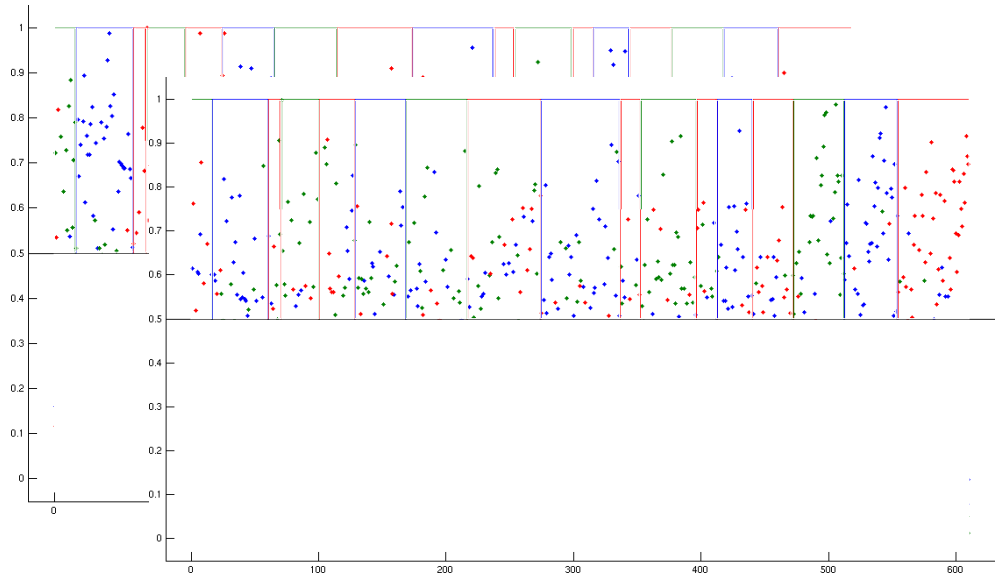
Anna Buttfield. *IDIAP*

Adapt the classifier in real time as the subject mentally controls the robot



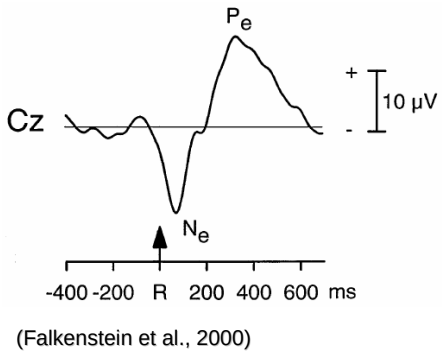
Left Right Word

On-Line Learning (cont)

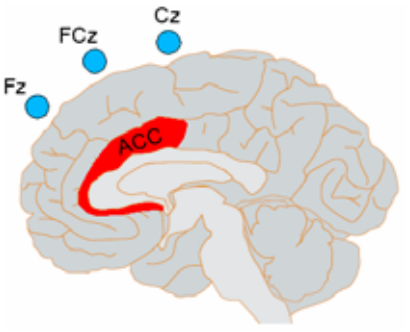


IV. You Got Me Wrong! — Recognition of Cognitive States

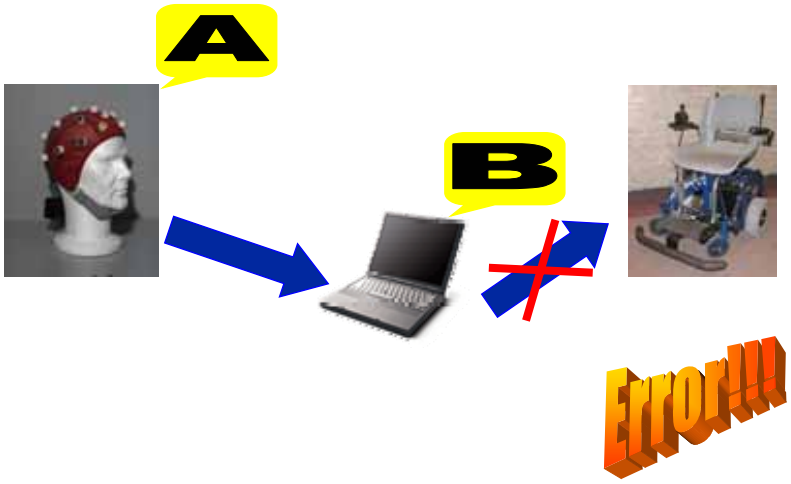
Pierre W. Ferrez. *IDIAP*



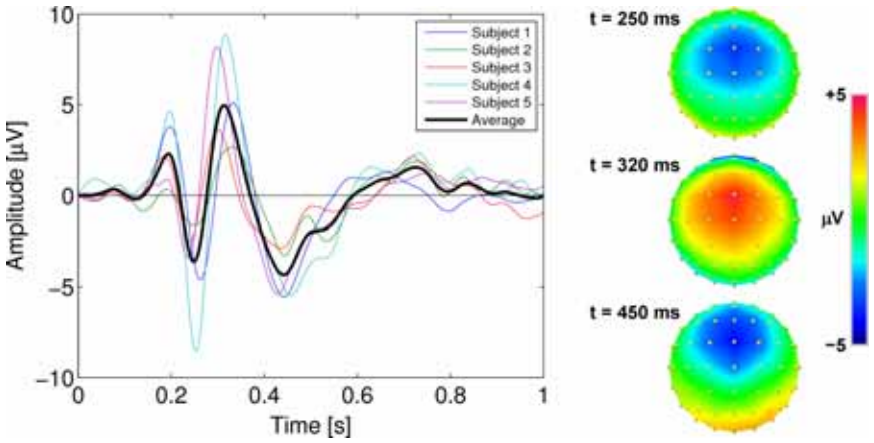
(Falkenstein et al., 2000)



Error Recognition



“Interaction” Error-related Potentials



- Reliability of interaction will increase tremendously …
  >70% bit rate transfer, on average!!

Conclusions: Towards Brain Technology

- ***MAIA*** project — radical departure from current assumptions to develop non-invasive neuroprostheses:

  estimated LFP, error-related potentials, on-line learning, adaptive shared autonomy, haptic feedback.

- ***EEG carries cognitive information*** — unique feature of the "brain channel":

  it conveys information about intents (mental commands) **AND** cognitive states (errors, alarms, attention, frustration, confusion, etc.) that are crucial for a purposeful interaction

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