3.2 'Controlling by Thought? – Brain Computer Interfaces and Embedded Brain Reading – An Introduction' (II-T-02)

Elsa Andrea Kirchner[(1) (2)]

(1) Universität Bremen, Arbeitsgruppe Robotik, Robert-Hooke-Straße 1, 28359 Bremen, Germany
(2) DFKI GmbH, Robotics Innovation Center, Robert-Hooke-Straße 1, 28359 Bremen, Germany

Contact: elsa.kirchner@dfki.de

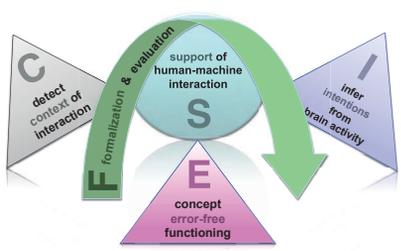
Abstract

Machines, like PCs or robots, can be controlled by brain signals. Brain activity is often used to reestablish communication and control for human that are disabled to move or to communicate. Brain computer interfaces, which are used to link the human brain with a machine, do often require the attention of the human to enable explicit control. For such approaches it is unimportant how and which brain signal is used. Highest relevance has robustness and easiness. Using brain activity for the support of healthy people brings new challenges. Adding the link between brain and machine must not require extra cognitive resources from the human. Thus, for many applications a rather passive approach that uses brain activity implicitly should be chosen. However, beside the question on how to use brain activity, i.e., implicitly or explicitly, other questions are also relevant for the development of intelligent and intuitive interfaces for control or support. For example, other technical or physiological data can improve reliability but bring along challenges for signal processing and classification and must be handled by adequate software frameworks.

Controlling by Thought?

Brain Computer Interfaces and Embedded Brain Reading – An Introduction

Project Day Work Group
Interaction & ROCON
Dr. Elsa A. Kirchner
Robotics Lab, University of Bremen and
DFKI RIC



Universität Bremen

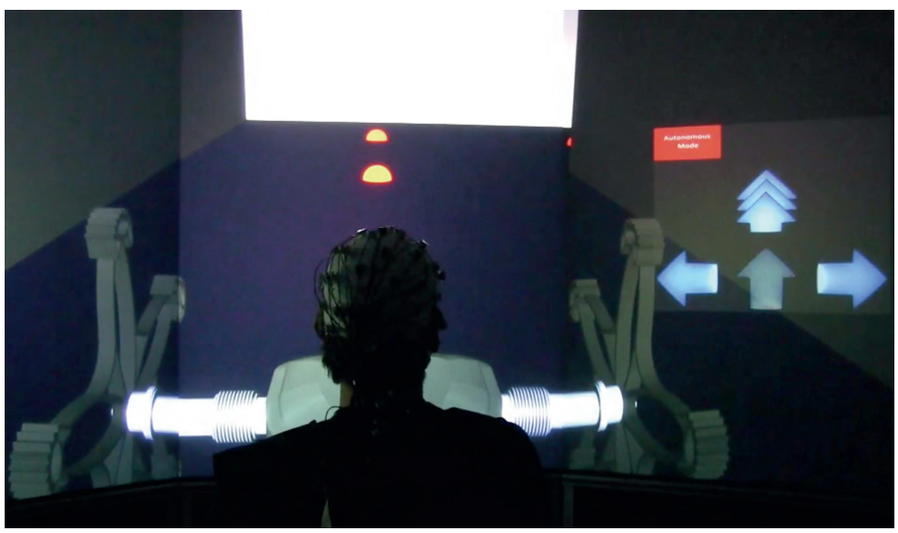
What Kind of Interface?

BCI: Brain-Computer Interface

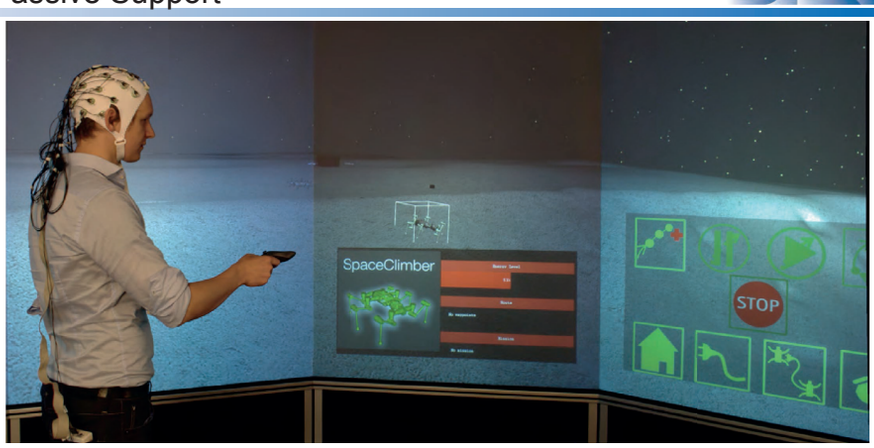
- A brain computer interface (BCI) is classically used to control a machine or PC:

„ A BCI is a direct link or interface between brain and PC that recognizes certain patterns in the brains activity that are translated into signals for communication and control.“ (adapted from Wolpaw et al. 2002)

What Kind of Interface?
MonsterMind BCI



What Kind of Interface?
Passive Support



- e.g., adaptation of an MMI with respect to mental workload
  - can be based on behavioral data (missing of responses, response time etc.) or
  - **biosignals**

What Kind of Interface?
Biosignals versus Psychophysiological Data

- **Biosignal**: a signal that is caused by a biological system or subsystem, i.e., by its biological activity
  - biological system: e.g., a human or … a bacteria
  - subsystem: e.g., the humans brain, skin, muscles, eyes....
- A biosignal can be interpreted to tell us something about the biological system,
  - e.g., its behavior or state, and can thus be a **psychophysiological** measure.
  - It can be used for affective computing, for e.g. gaming, that incorporates real-time software **adaption** to the psychophysiological activity of the user
- Biosignals can be used to **control a machine**,
  - e.g., by eye movement or brain signals in classic brain computer interfaces (BCIs)

Psychophysiological Data
Active Control and Passive Adaptation

psychophysiological data* can be applied for:

*like muscle activity, pulse, brain activity…

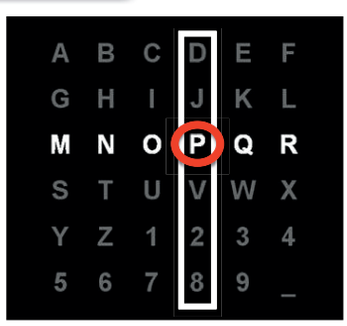
active control | **passive adaptation**

brain activity is used for:

P300 Speller (Farwell and Donchin, 1988)

active
brain-computer interfaces (BCI)[1]

explicit
information transfer



[1]Farwell and Donchin, 1988; Pfurtscheller, 2000; Wolpaw et al., 2002; Allison et al., 2007
[2]Pope et al., 1995; Allanson and Fairclough, 2004
[3]Blankertz et al., 2002; Zander et al., 2009; Haufe et al., 2011

https://kaggle2.blob.core.windows.net/competitions/kaggle/4043/media/P300_Speller.mp4

Psychophysiological Data
Active Control and Passive Adaptation

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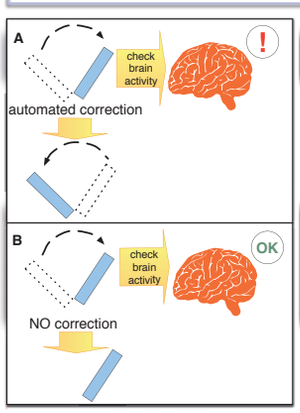

passive adaptation

biocybernetic adaptation[2]
passive BCIs[3]

error-detection (Blankertz et al., 2002)

implicit information transfer

[1]Farwell and Donchin, 1988; Pfurtscheller, 2000; Wolpaw et al., 2002; Allison et al., 2007
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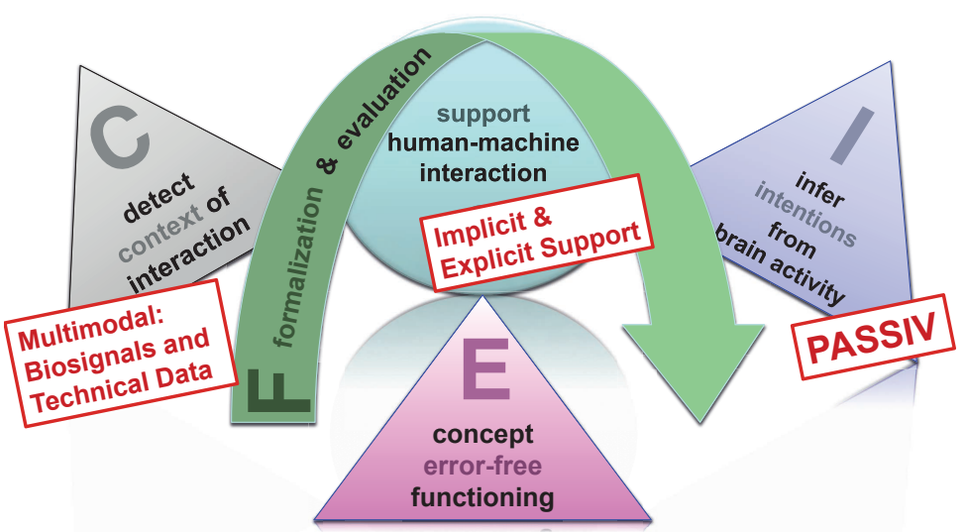
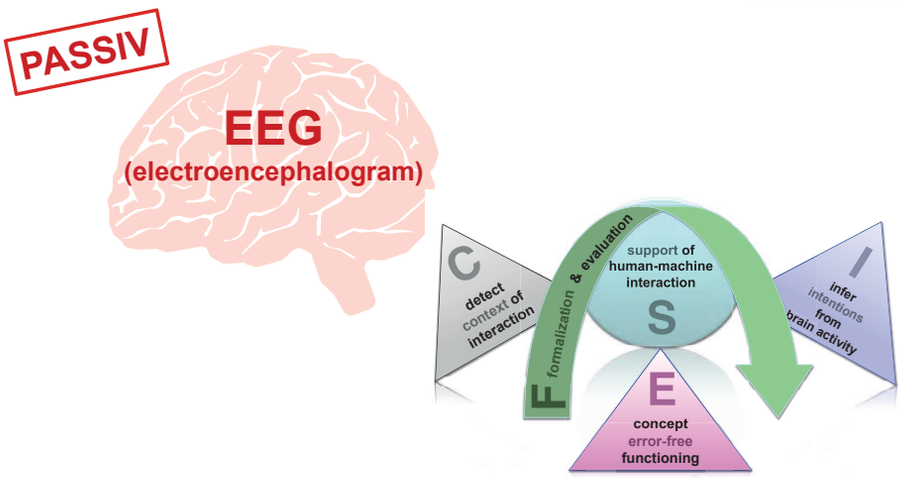
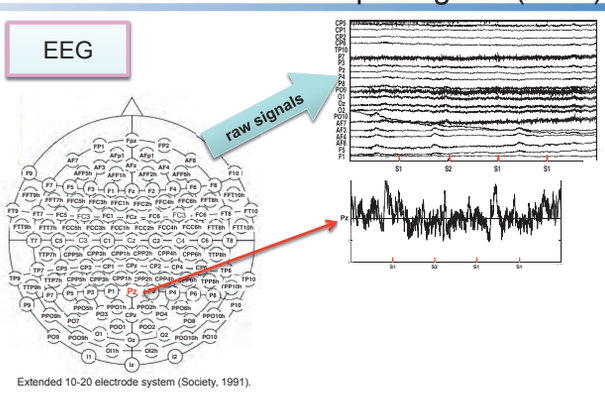
Concept
Embedded Brain Reading



Concept
Embedded Brain Reading



Theoretical Background
The Human Electroencephalogram (EEG)



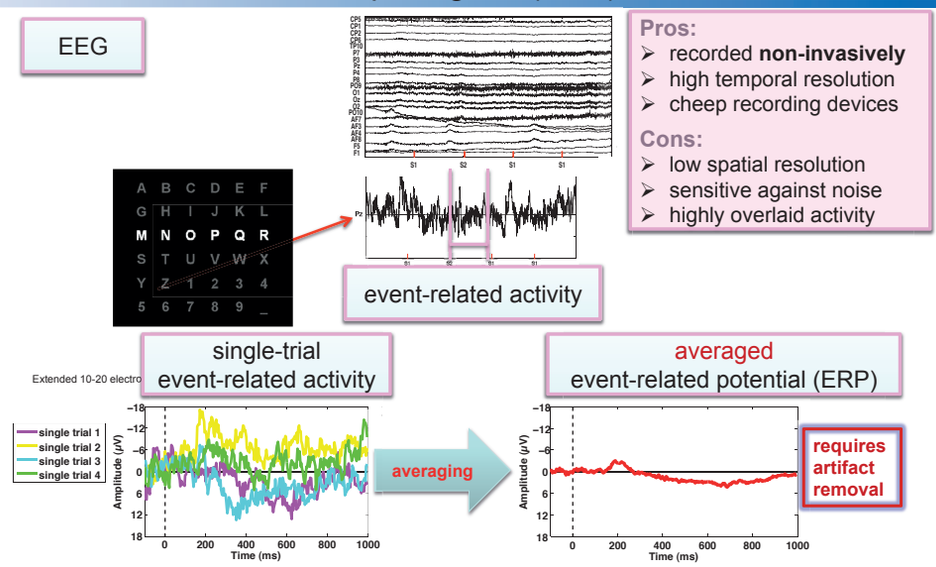
Extended 10-20 electrode system (Society, 1991).

Pros:
- recorded **non-invasively**
- high temporal resolution
- cheep recording devices

Cons:
- low spatial resolution
- sensitive against noise
- highly overlaid activity

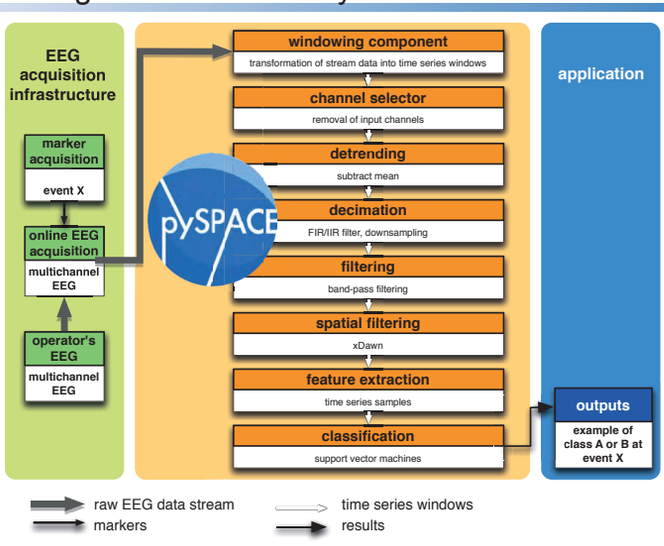
Theoretical Background

The Human Electroencephalogram (EEG)



pySPACE

Single-Trial EEG Analysis



supervised learning **requires**:

- **training data**

must be **optimized** with respect to:

- **choice of data**
- **training procedures**

Krell et al., 2013

Concept
Why Using EEG Data?

But why using brain activity?

The analysis of brain activity can serve as *a window into the human mind or brain*[1] and does even enable to *uncover preconscious intention*, like early, preconscious movement intention.[2]

The analysis of brain activity as a **covert** physiological measure enables *permanent access to a human's state* unlike **overt** behavioral data.[3]

[1]Coles, 1989
[2]Libet et al., 1983; Shibasaki and Hallett, 2006
[3]Gerson et al., 2006

Embedded Brain Reading
Applications

Literature used and for study

- Allanson, J. and Fairclough, S. (2004). A research agenda for physiological computing. Interacting with Computers, 16(5):857–878.
- Arthurs, O. J. and Boniface, S. (2002). How well do we understand the neural origins of the fMRI BOLD signal? Trends in Neurosciences, 25(1):27–31.
- Asano, E., Juhász, C., Shah, A., Muzik, O., Chugani, D. C., Shah, J., Sood, S., and Chugani, H. T. (2005). Origin and propagation of epileptic spasms delineated on electrocorticography. Epilepsia, 46(7):1086–1097.
- Blankertz, B., Dornhege, G., Krauledat, M., Schröder, M., Williamson, J., Murray-Smith, R., and Müller, K.-R. (2006). The Berlin Brain-Computer Interface presents the novel mental typewriter Hex-o-Spell. In Verlag der Technischen Universität Graz, pages 108–109.
- Blankertz, B., Schäfer, C., Dornhege, G., and Curio, G. (2002). Single trial detection of eeg error potentials: A tool for increasing bci transmission rates. In Dorronsoro, J., editor, Artificial Neural Networks - ICANN 2002, volume 2415 of Lecture Notes in Computer Science, pages 1137–1143. Springer: Berlin, Heidelberg.
- Berger, H. (1929). Über das Elektroenkephalogramm des Menschen. Archiv für Psychiatrie und Nervenkrankheiten, 87:527–570.
- Birbaumer, N. (2006). Breaking the silence: Brain-computer interfaces (BCI) forcommunication and motor control. Psychophysiology, 43(6):517–532.
- Clarke, Jr., E. M., Grumberg, O., and Peled, D. A. (1999). Model Checking. MIT Press.
- Cohen, D. (1968). Magnetoencephalography: Evidence of Magnetic Fields Produced by Alpha-Rhythm Currents. Science, 161(3843):784–786.
- Coles, M. (1989). Modern Mind-Brain Reading: Psychophysiology, Physiology, and Cognition. Psychophysiology, 26(3):251-269.
- Deecke, L., Scheid, P., and Kornhuber, H. H. (1969). Distribution of readiness potential, pre-motion positivity, and motor potential of the human cerebral cortex preceding voluntary finger movements. Experimental Brain Research, 7(2):158–168.
- Farwell, L. and Donchin, E. (1988). Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. Electroencephalography and Clinical Neurophysiology, 70(6):510–523.
- Gerson, A. D., Parra, L. C., and Sajda, P. (2006). Cortically-coupled computer vision for rapid image search. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2(14):174-179.
- Gray, C. M., Maldonado, P. E., Wilson, M., and McNaughton, B. (1995). Tetrodes markedly improve the reliability and yield of multiple single-unit isolation from multi-unit recordings in cat striate cortex. Journal of Neuroscience Methods, 63(1-2):43–54.

Literature used and for study

- Haufe, S., Treder, M. S., Gugler, M. F., Sagebaum, M., Curio, G., and Blankertz, B. (2011). EEG potentials predict upcoming emergency brakings during simulated driving. Journal of Neural Engineering, 8(5):056001.
- Hubel, D. H. andWiesel, T. N. (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. The Journal of Physiology, 160(1):106–154.
- Huettel, S. A., Song, A. W., and McCarthy, G. (2009). Functional Magnetic Resonance Imaging (2 ed.). Massachusetts: Sinauer.
- Kirchner, E. A. and Drechsler, R. (2013a). A Formal Model for Embedded Brain Reading. Industrial Robot: An International Journal, 40(6):530–540.
- Kirchner, E. A., Kim, S. K., Straube, S., Seeland, A., Wöhrle, H., Krell, M. M., Tabie, M., and Fahle, M. (2013d). On the applicability of brain reading for predictive human-machine interfaces in robotics. PLoS ONE, 8(12):e81732.
- Kirchner, E. A., Tabie, M., and Seeland, A. (2014). Multimodal movement prediction- towards an individual assistance of patients. PLoS ONE, 9(1):e85060.
- Kornhuber, H. H. and Deecke, L. (1965). Hirnpotentialänderungen bei Willkürbewegungen und passiven Bewegungen des Menschen: Bereitschaftspotential und reafferente Potentiale. Pflügers Archives, 284:1–17.
- Krell, M. M., Straube, S., Seeland, A., Wöhrle, H., Teiwes, J., Metzen, J. H., Kirchner, E. A., and Kirchner, F. (2013). pySPACE - a signal processing and classification environment in Python. Frontiers in Neuroinformatics, 7(40). https://github.com/pyspace.
- Libet, B., Gleason, C. A., Wright, E. W., and Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act. Brain, 106(Pt 3):623-642.; Shibasaki, H. and Hallett, M. (2006). What is the Bereitschaftspotential? Clinical Neurophysiology, 117(11):2341-2356.
- Okada, Y. C. (1983). Neurogenesis of Evoked Magnetic Fields. In Biomagnetism: an Interdisciplinary Approach, pages 399–408. Plenum Press: New York.
- Palmini, A. (2006). The concept of the epileptogenic zone: a modern look at penfield and jasper's views on the role of interictal spikes. Epileptic Disorders, 8 Suppl 2:S10–15.
- Pfurtscheller, G. (2000). Brain oscillations control hand orthosis in a tetraplegic. Neuroscience Letters, 292(3):211–214.
- Pfurtscheller, G., Allison, B. Z., Bauernfeind, G., Brunner, C., Solis Escalante, T., Scherer, R., Zander, T. O., Mueller-Putz, G., Neuper, C., and Birbaumer, N. (2010). The hybrid BCI. Frontiers in Neuroscience, 4(3).
- Phelps, M., Hoffman, E., Mullani, N., and Ter-Pogossian, M. (1975). Application of annihilation coincidence detection to transaxial reconstruction tomography. Journal of Nuclear Medicine, 16(3):210–224.

Literature used and for study

- Pope, A. T., Bogart, E. H., and Bartolome, D. S. (1995). Biocybernetic system evaluates indices of operator engagement in automated task. Biological Psychology, 40(1–2):187–195.
- Shibasaki, H. and Hallett, M. (2006). What is the Bereitschaftspotential? Clinical Neurophysiology, 117(11):2341–2356.
- Seeland, A., Woehrle, H., Straube, S., and Kirchner, E. A. (2013b). Online movement prediction in a robotic application scenario. In 6th International IEEE EMBS Conference on Neural Engineering (NER), pages 41–44, San Diego, California.
- Siapas, A. G., Lubenov, E. V., and Wilson, M. A. (2005). Prefrontal phase locking to hippocampal theta oscillations. Neuron, 46(1): 141 – 151.
- Society, A. E. (1991). Guidelines for standard electrode position nomenclature. Journal of Clinical Neurophysiology, 8(2):200–202.
- Sutton, S., Braren, M., Zubin, J., and John, E. R. (1965). Evoked-potential correlates of stimulus uncertainty. Science, 150(3700): 1187–1188.
- Squires, N. K., Squires, K. C., and Hillyard, S. A. (1975). Two varieties of longlatency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 38(4):387–401.
- Ulbert, I., Halgren, E., Heit, G., and Karmos, G. (2001). Multiple microelectroderecording system for human intracortical applications. Journal of Neuroscience, 106(1):69 – 79.
- Verleger, R. (1997). On the utility of P3 latency as an index of mental chronometry. Psychophysiology, 34(2):131–156.
- Wöhrle, H. and Kirchner, E. A. (2014). Online Detection of P300 related Target Recognition Processes During a Demanding Teleoperation Task. In Proceedings of the International Conference on Physiological Computing Systems, (PhyCS 2014), Lissabon, Portugal. SCITEPRESS Digital Library.
- Wolpaw, J. R., Birbaumer, N., McFarland, D. J., Pfurtscheller, G., and Vaughan, T. M. (2002). Brain-computer interfaces for communication and control. Clinical Neurophysiology, 113(6):767-791.
- Zander, T. O., Kothe, C.,Welke, S., and Roetting, M. (2009). Utilizing Secondary Input from Passive Brain-Computer Interfaces for Enhancing Human-Machine Interaction. In Proceedings of the 5th International Conference on Foundations of Augmented Cognition. Neuroergonomics and Operational Neuroscience: Held as Part of HCI International 2009, FAC '09, pages 759–771. Springer: Berlin, Heidelberg.
- Zschocke, S. (1995). Klinische Elektroenzephalographie. Springer: Berlin, Heidelberg.