Cognitive Technical Systems

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Electrophysiological measurements like Electroencephalography (EEG) and Electromyography (EMG) enable us to measure human behavior by capturing neural and muscular activity. While traditional applications of those techniques were developed for medical and psychological purposes, since a few years they are also applied in the design of innovative human-machine interfaces. They allow a very direct measurement of user behavior and can also capture internal mental states which influence current and future behavior and which are not directly visible by other means. This presentation will show a number of state-of-the-art EEG- and EMG-based applications developed at the Cognitive Systems Lab.

EEG-based Brain-Computer-Interfaces (BCIs) are often categorized into two groups: Active BCIs are interfaces which allow direct and voluntary control of a system using natural or artificial "mental commands". In contrast, passive BCIs constantly measure the user's natural cognitive processes and react to them in an appropriate way without explicit user intervention. State-of-the-art examples of active BCIs are systems for spatial control. They are based on the paradigm of motion imagery, i.e. the imagination of movement of arm or leg. Imagined motion triggers characteristic activation patterns in the motor cortex which can be automatically detected. Traditional systems can recognize a small set of discrete motions. We present our current BCI for spatial control which includes speed trajectory reconstruction of continuous hand movement of complex natural movements.

A major application of passive BCIs is the recognition of mental workload. Using machine learning techniques, a system learns the most relevant frequency bands to discriminate low workload and high workload conditions. As the workload level influences behavior and performance of the user, the system adapts its own interaction strategy to make optimal use of the remaining cognitive resources of the user. We evaluate this system on a large corpus of over 150 participants in a driving scenario and achieved an accuracy of 82% for the person-independent workload recognition and an accuracy of more than 90% for person-dependent but session-independent recognition in another study. We also present results of a study which shows that implementing a workload adaptive interaction system improves both effectiveness and efficiency compared to a workload-oblivious system. Another application of passive BCIs deals with tracking the execution of cognitive processes. To optimally support the user during a complex task, it is useful to know which cognitive processing stages (perception, memory retrieval, attention shift …) are currently active. One example of such a system is an error-BCI which detects Error Related Potentials (ERPs) in the EEG signal. Those potentials occur when the user becomes aware of a mistake during interface operation or notices erroneous behavior of the system. Detecting ERPs allows the system to proactively recover from errors in the workflow. In this presentation, we show a gesture recognition system that uses this technique to automatically detect its recognition errors from single trials and proactively recovers from error states.

Electrophysiological signals are often polluted with biological and technical artifacts. A major challenge of modern BCI systems which are employed in uncontrolled environments and deal with complex tasks is the removal of artifacts and the identification of task-relevant brain activity. Techniques for signal decomposition and blind source separation like Independent Component Analysis are employed to isolate different influences on the signal and to separate relevant from irrelevant contributions. This way, we cannot only remove the influence of typical artifacts like eye blinks but also extract the most relevant components related to the task.

When dealing with tasks involving or allowing motor execution for control, EMG-based user interfaces are often an alternative to BCIs. An example are Silent Speech Interfaces which use facial surface EMG to record facial activity of the user while speaking. Using state-of-the-art speech recognition technology, these signals can be evaluated to transcribe the user's speech input to the system even if it is uttered without producing audible sounds. Such system is useful in noisy environments, when silence is required (e.g. during meetings) or when the user cannot produce audible speech after a laryngectomy.