BCI RESEARCH AT COLORADO STATE UNIVERSITY

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Brain-computer interface research at Colorado State University consists of several related efforts. Much of our work is focused on the discovery of low-dimensional characterizations of multi-channel, spontaneous, EEG signals that are reliable discriminators of cognitive activity during common mental tasks, such as mental multiplication, rotation of three-dimensional objects, and mentally writing a letter. To-date, our best results are obtained by modeling signals from each channel with sixth-order, autoregressive (AR) models and classifying the AR coefficients with feedforward neural networks. We trained neural networks to classify half-second segments of six-channel, EEG data into one of five classes corresponding to five mental tasks performed by one subject. Using the AR representation and averaging over consecutive segments, an average of 72% of the test segments are correctly classified; for some test sets 100% are correctly classified.

We are currently investigating several other techniques for dimensionality reduction and classification. Subspace methodologies, such as the Karhunen-Loeve (KL) transform, are generally useful tools for the characterization of high-dimensional data sets. Two approaches that have received considerably less attention than the KL transform are the maximum signal fraction method and canonical correlation analysis. In a comparative study of subspace methods, we find interesting differences in how each method extracts noise and other components that facilitate the discrimination of signals into classes corresponding to mental task. The subspace methods result in linear transformations of the data. Our preliminary results suggest that the combination of these linear transformations with fairly simple classifiers, including linear discriminant analysis (LDA), may be sufficient for solving some BCI classification problems. Careful comparisons of LDA, neural networks, and support vector machines show little statistical significance in the classification performance.

In the work summarized above, analysis is performed off-line after EEG recording. We are currently experimenting with an inexpensive EEG acquisition and analysis system based on the 16-channel, MindSet-1000 EEG amplifier ($2000) connected via a SCSI interface to a laptop computer, and custom software running in a Linux environment. Recently this system was used to acquire 10-channels of EEG from subjects listening to paired tones of varying dissonance. Analysis of the signals identified the electrode pairs whose signals were most coherent at various frequencies and how this differed between the most dissonant and least dissonant tones. This system will be used in biofeedback experiments in which subjects will observe the classification result and confidence in real time, giving subjects the opportunity to modify their cognitive behavior to increase the classification accuracy.

In joint work with Colorado State University's Center for Biomedical Research in Music (CBRM), our lab is also engaged in basic research into the neural dynamics associated with auditory working memory. CBRM has extensive clinical results demonstrating the value of music for rehabilitating impaired motor function; a similar regime may ameliorate cognitive dysfunction. Working memory is our focus because of its critical role in most cognitive functions. Our analysis of the EEG recorded during auditory working memory tasks is based on custom, high-resolution frequency bands that we classify using support vector machines. A genetic algorithm is used to search the high-dimensional feature space for the feature subsets that best dissociate conditions. The genetic algorithm is used in a "wrapper" fashion, searching over feature subsets using the support vector machine's classification accuracy as a “fitness” measure.

TOWARDS BETTER SOFTWARE COMPONENTS FOR BRAIN-COMPUTER INTERFACES

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Most existing Brain-Computer Interfaces (BCIs) are monolithic creations that are designed to run on special hardware. Recently, interest has increased in making BCI systems flexible (see bci2000.org for an example of another flexible system). Flexible systems allow both hardware and software components in the system to be swapped in and out with minimal changes. Using techniques from software engineering, we have created components for data acquisition, communications, signal processing, and user applications. These components have been successfully integrated to form a BCI that has been used for tasks as diverse as on-line P3 recognition and feedback in virtual reality, playing games with eye movement control, and gamma wave experiments. With this system, it is possible to change signal processing without altering the main BCI system program code. We will discuss current work on assuring system reliability as well as the benefits of being able to change user applications easily.