Overcoming Barriers in Noninvasive Brain-Computer Interfaces

Elliott Forney, Kathleen Ericson, Charles Anderson, Shrideep Pallickara,
William Gavin, Patricia Davies, Marla Roll, Zachary Cashero

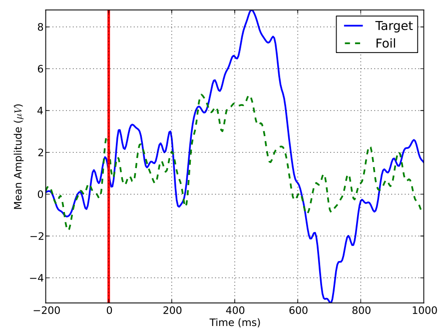
Colorado State University, Fort Collins, CO, USA
Contact: idfah@cs.colostate.edu

Although many advances in brain-computer interface (BCI) technology have been made in recent years, there are still a number of barriers that continue to impede the widespread adoption of BCI into commercial devices. At The Colorado State University Brain-Computer Interface Laboratory, we are taking a practical, multifaceted approach toward addressing these issues.

The bulk of our research is focused on improving two BCI paradigms: P300 spellers and classification of imagined mental tasks. We believe that improvements in P300 spellers may have an immediate impact on assistive technology while the classification of spontaneous imagined mental tasks may lead to a stimulus-free BCI that can be operated fluidly and with multiple degrees of freedom. In the following sections, we outline the research we are currently performing to overcome the obstacles associated with implementing these paradigms.

Comparison of EEG Systems

One of the most important barriers to overcome in the development of BCI is the continued testing and transfer of this technology into real-world environments. Since those with motor disabilities and even locked-in syndrome are likely the first target demographics for BCI, it is extremely important that BCI be able to function for these populations and in their home environments.

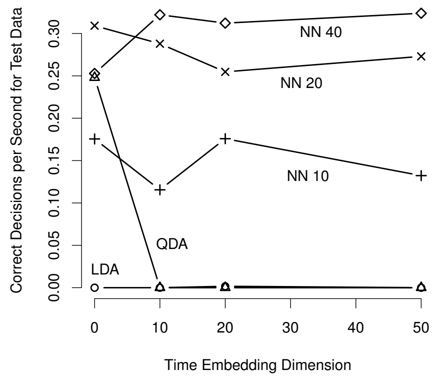


To this end, we are comparing the performance of three EEG acquisition systems using both the P300 and imagined mental task paradigms. This comparison is being performed among users with severe motor disabilities in their home environments as well as able-bodied users in laboratory settings. The systems being compared include the NeuroPulse Mindset 24R, an inexpensive 19-channel passive system, the g.tec g.MOBILab+ with g.GAMMAsys active electrodes, a portable 8-channel system, and the Biosemi ActiveTwo, a high-end 32-channel active system. Preliminary results suggest that it is difficult to observe P300's in disabled users in real-world environments, increasing the importance of identifying robust EEG acquisition systems. It is encouraging, however, that the highly portable g.MOBILab+ system often yields some of the most prominent P300 peaks. To the right we see the grand-average of event related potentials from four subjects with motor disabilities using the g.MOBILab+ in home environments.

Additionally, a spectral analysis reveals that all three systems are far more vulnerable to 60Hz interference in home environments. It also appears that the higher bandwidth ActiveTwo system allows the introduction of 60Hz harmonics and, possibly, some aliasing. We have also observed an increase in EMG artifacts and experienced some difficulty maintaining stable connections in real-world environments. Users consistently report that their personal preference is for the small and easy to apply g.MOBILab+ system.

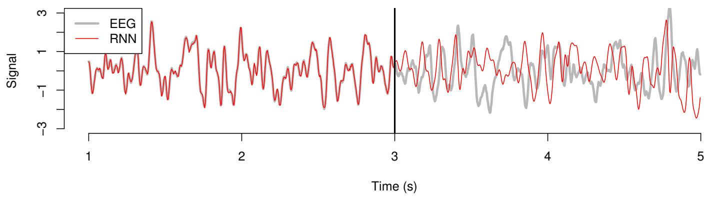
Pattern Recognition Algorithms

Our experience suggests that the best classification algorithms for use in BCI are robust, non-linear classification algorithms combined with careful regularization, preprocessing and feature generation.



Recently, we investigated the use of non-linear Feedforward Artificial Neural Networks (NN) for the classification of imagined mental tasks (*Journal of Neural Engineering*, Vol. 8, No. 2, 025023). This approach was combined with time-delay embedding, i.e., combining multiple timesteps into each sample, in order to capture temporal information. An M-ary Sequential Probability Ratio Test (MSPRT) was also used to incrementally accumulate evidence before assigning class labels. This yields a BCI that is more robust to artifacts and user distraction since it will not perform an action until it has sufficient confidence in a user's intent. To the right, we see that this approach significantly outperforms two statistical classifiers, Linear Discriminant Analysis (LDA) and Quadratic Discriminant Analysis (QDA), requiring about three seconds per correct decision with four imagined mental tasks. Performance is described as correct decisions per second in order to better capture user experience with the variable decision rate of MSPRT.

We have also investigated the use of Recurrent Artificial Neural Networks (RNN) for classifying imagined mental tasks (Elliott Forney, CSU Master's Thesis, 2011), (*Proceedings of the International Joint Conference on Neural Networks*, July 31–August 5, 2011). In addition to being able to identify non-linear patterns, RNN have state and are able learn temporal patterns without the need for time-delay embedding or features in the frequency domain.

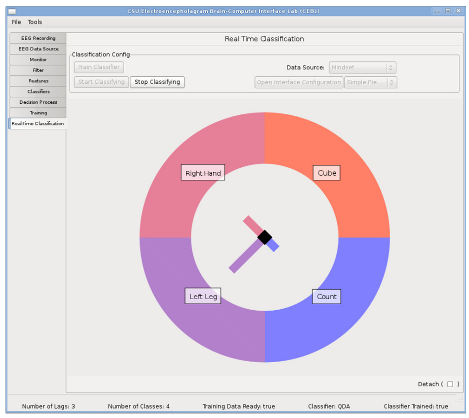


We have demonstrated that RNN are able to forecast EEG a single step ahead in time with an error as low as 1.18% of the signal range. We have also shown that when a feedback loop is placed between the output and input layers of an RNN, it can autonomously generate a signal that is very similar to true EEG. A spectral analysis using continuous wavelet transforms supports this assertion. To the right, we see an Elman Network forecasting EEG until the three second mark, at which point the RNN begins autonomously generating signals using only its previous predictions.

We have also shown that RNN can be used to classify EEG using a generative approach. A separate RNN is trained to forecast EEG recorded during each of the mental tasks to be classified. These networks can be viewed as experts on forecasting EEG signals from their respective classes. A previously unseen signal can then be classified by assigning the class label associated with the RNN that produces the lowest forecasting error. In offline studies we have achieved an information transfer rate as high as 34.5 bits per minute in a subject with a C4 complete spinal cord lesion.

Recently, our group has also demonstrated that blind source separation techniques, such as Maximum Noise Fraction (MNF), Principal Components Analysis (PCA) and Independent Components Analysis (ICA), can improve the classification accuracy of a P300 speller by roughly 2-4% when a small number of channels are used, the ideal for portable BCI (Zach Cashero, CSU Master's Thesis, 2011). Additionally, this work has shown that feature selection algorithms can consistently improve P300 speller performance by selecting user-specific channels in systems with as many as 64 channels.

Modular and Real-Time BCI Software



An important part of overcoming the current practical limitations of BCI is the development of software platforms that can combine state-of-the-art methods into a single unified package. Such a software package must function in real-time, operate on portable hardware and support popular EEG acquisition systems. Furthermore, BCI software platforms should utilize high-level languages and modular programming practices so that classifiers, filters, feature selection algorithms and user interfaces can be added quickly and easily.

In order to achieve this goal, our research group has begun a complete rewrite of The CSU EEG and BCI Lab (CEBL) in the Python programming language. An alpha release of CEBL 3.x can be expected to be released in late 2012 and will include a modular architecture and straightforward user interface. In the image to the right, we see a simple pie menu in CEBL in which a user moves a bar toward the instruction they wish to issue by imagining a mental task.

EEG Streams and Cloud Computing

As BCI become more mainstream and find their way into portable devices, it seems likely that much of the computation involved will be offloaded onto remote servers, as is the case with Apple's Siri voice recognition system. Along these lines, we have begun to investigate real-time streaming and classification of EEG using Granules, a cloud processing framework currently developed at Colorado State University that is particularly well-suited for processing streaming data. The software we have developed for Granules uses a Feedforward Neural Network with time-delay embedding to assign class labels (*Proceedings of the 2010 IEEE Second International Conference on Cloud Computing Technology and Science*, pp. 185–192, awarded best student paper). Additionally, our software now supports robust fault tolerance in order to prevent disruptions in service.

In our recent work, we have used simulated 19-channel EEG streams sampled at 512Hz, obtained by repeating EEG recorded while a user performed four imagined mental tasks, to demonstrate that our cloud processing software is capable of supporting as many as 1,400 simultaneous users on a cluster of 40 machines. Classification is easily achieved in real-time with a round-trip response time of less than 250ms for over 99% of requests. We expect that this technology will lead to the development of sophisticated BCI on portable lightweight hardware, such as smart phones and tablets.